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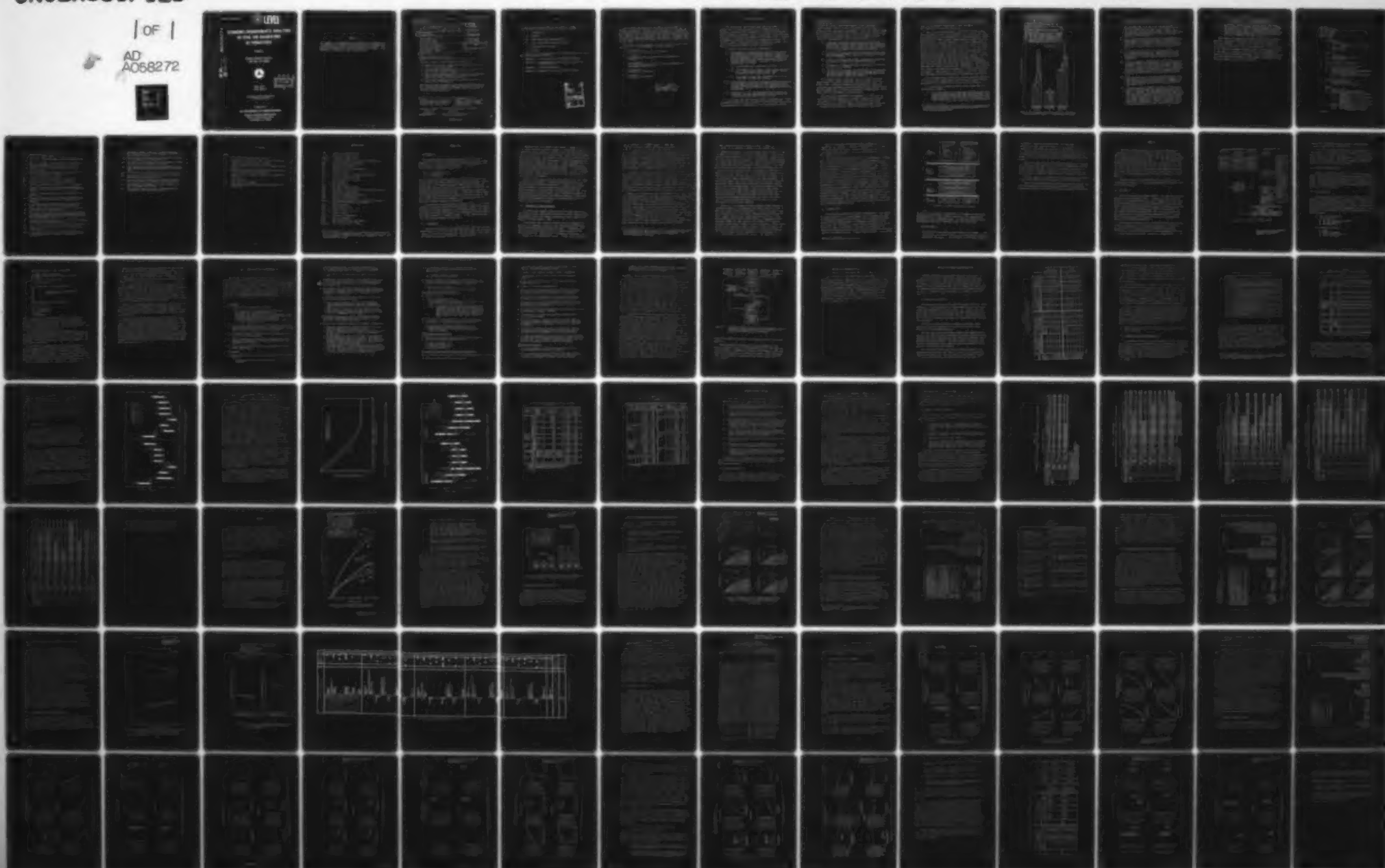

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ECONOMIC REQUIREMENTS ANALYSIS OF CIVIL AIR NAVIGATION ALTERNATIVES

Volume I

Systems Control, Inc. (Vt.)
Palo Alto, Ca. 94304

APRIL 1978
FINAL REPORT

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16. Abstract

This report summarizes a study whose objectives were to:

(1) Develop a life cycle cost computer model to evaluate various alternative civil aviation navigation systems;

(2) Project government implementation and recurring costs and user avionics costs associated with each alternative,

(3) Develop rational implementation/transition scenarios for various combinations of the systems to provide civil air navigation coverage in the CONUS, Alaska, Oceanic and Off-shore regions, AND

(4) Make an initial assessment of the economic impact upon the FAA and civil aviation users for each scenario.

Alternatives evaluated were VOR/DME, Loran-C, Omega, Differential Omega, and GPS. The least costly alternative, based upon combined civil user and FAA costs, was found to be continued use of VOR/DME. Sole use of GPS was found to be the most costly alternative.

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FOREWORD

This report is published in two volumes. Volume I presents the findings in six sections plus an executive summary:

I. INTRODUCTION

II. APPROACH

III. STUDY GUIDELINES AND GROUND RULES

IV. NAVIGATION SYSTEM CHARACTERIZATION

V. IMPLEMENTATION SCENARIOS

VI. RESULTS

Volume II contains appendices with supporting data and methodology descriptions as follows:

APPENDIX A: FAA AND USER COST ESTIMATION METHODOLOGY

APPENDIX B: DEVELOPMENT OF RAANS NAVIGATION SYSTEM AND AVIONICS COSTS

APPENDIX C: BACKUP STUDY RESULTS

APPENDIX D: COMPLETE LIFE CYCLE COST MODEL PRINTOUT

ACKNOWLEDGEMENTS

This study, performed for the Federal Aviation Administration, Office of Aviation System Plans, resulted from the contributions of many individuals. In particular, appreciation is extended to Mr. Norman Weil, the FAA COTR, and the FAA members of the Requirements Analysis of Air Navigation Systems Support Team; specifically, J.W. Bradley (AEM), S.I. Rothschild (ASP) and A.A. Simolunas (ARD), for their assistance and guidance. Appreciation is also extended to G.S. Mercer (FAA-AVP) for providing the aviation forecasts used in this study.

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  (Technical Publications)

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EXECUTIVE SUMMARY

The study effort discussed in this report encompassed a cost analysis of civil air navigation system alternatives and was conducted to assist the FAA in meeting its on-going commitments to fully evaluate the economic impact of potential system selection decisions. The overall objectives of this effort were to develop a mechanism to provide the FAA with a capability to assess the economic impact of proposed alternative navigation systems and to make an initial assessment of those alternatives.

To this end the following was accomplished:

(1) Development of a computer model which can be operated by the FAA to perform economic analyses. This model can determine costs (including the dollar impact on the various components of the "user" civil aviation community) for specified alternative navigation systems or combinations of systems. The model is structured on a modular basis to permit:

  (a) the incorporation of revisions in basic cost data,

  (b) the evaluation of changes in basic policy decisions, i.e., share of FAA costs to help support systems operated by other organizations, and

  (c) adjustment of other key parameters such as inflation rate or transition periods.

(2) Identification, collection, refinement and/or development of the inputs required to drive the model and make an initial economic assessment of the technically viable alternatives, based on the most reasonable data available at the time.

(3) Definition of a set of implementation and transition scenarios, and the determination of the resulting NAS user and FAA costs and cost sensitivities.

Prior to the activity described herein a complementary effort, implemented under the same contract by the FAA Systems Research and Development Service, developed civil air navigation performance

requirements for the CONUS, Alaska, CONUS off-shore, Alaska off-shore and oceanic operating regions. It then "tested" each of the alternatives (Omega, differential Omega, Loran-C and GPS) to ascertain which systems in each region could satisfy the established civil air navigation requirements. This study effort, under the contractual supervision of the Office of Aviation System Plans, then performed an economic analysis of the alternatives found to satisfy the requirements. These alternatives were:

(1) A baseline "no change" scenario wherein the current CONUS and Alaska VOR system evolved into the second generation VOR. Oceanic and off-shore civil air navigation was provided by Omega. For comparison purposes, evolution to an upgraded VOR system was also included.

(2) Initial use of baseline systems followed by a transition to a differential Omega system in the Alaska and Alaska off-shore regions.

(3) Initial use of baseline systems followed by a transition to a Loran-C system in all regions but oceanic.

(4) Initial use of baseline systems followed by a transition to a GPS in all regions.

(5) Initial use of baseline systems followed by a transition to a GPS in all regions while still maintaining second generation VOR in CONUS and Alaska (for NAS users with low cost enroute navigation avionics).

The economic impacts identified were in the form of anticipated navigation system induced FAA and user annual costs, from 1978 to 2005. Potential alternative system benefits unrelated to the enroute navigation system requirements (e.g., non-precision approach capability), or those resulting from exceeding the requirements, were not considered in this analysis.

The FAA costs consisted of two elements: (1) the costs to bring the specified navigation system or systems up to an operational state, i.e., implementation costs, and (2) the annual recurring costs required to sustain system operations. These FAA cost elements were, however, limited to only those incremental

costs required to upgrade or modify alternative systems* or supply those services necessary to cause those systems to satisfy the civil air navigation requirements. Costs related to the baseline VOR system were borne solely by the FAA.

User costs were determined for each of 98 NAS user groups distinguished by their type of operation (air carrier, air taxi, executive/business and personal/other); operating regions (viable combinations of CONUS, Alaska, CONUS off-shore, Alaska off-shore and/or Oceanic); avionics category, i.e., grade (reflective of sophistication and capability); and type of aircraft (3-4 engine jet, 1-2 engine jet, propellor and helicopter). User costs were limited to the costs of purchasing enroute navigation avionics caused either by normal replacement cycles or by "forced" retrofitting to accommodate a specified transition schedule. Factors used in quantifying user costs included grade and number of avionics units installed, investment tax credit, depreciation, unit production base, and technology improvements. Inflation was factored into both FAA and user cost computations. The resulting cash outlay values were then discounted to obtain present value equivalents. Unless noted to the contrary, all costs cited in the following results/conclusions are undiscounted cash outlay.

The resulting range of NAS user, FAA and combined cumulative (1978-2005) costs determined for each of the navigation system alternatives are illustrated in the bar chart of Figure 1.

The significant conclusions which can be drawn from this study are as follows:

(1) Civil NAS users will be adversely affected by any transition from the present VOR system to alternative navigation systems, particularly GPS. Based upon the costs used herein, user cash outlay for GPS (assuming a 1985-1995 transition) is more than double that estimated for

*Includes those navigation systems expected to be implemented and operated by other governmental organizations primarily for non-civil aviation applications.

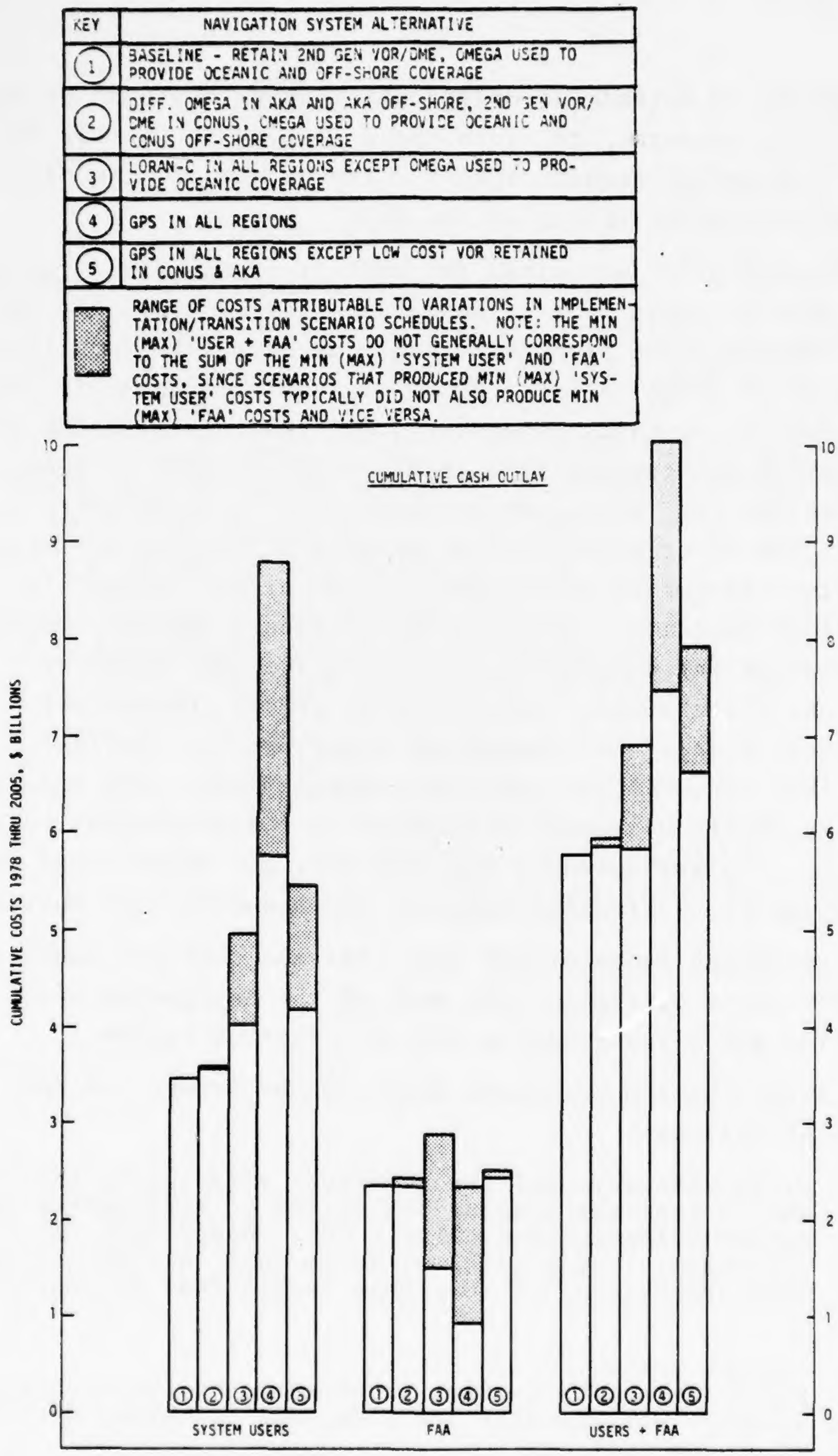

Figure 1 Air Navigation System Alternatives - Cost Comparison (Annual Inflation Rate = 7%; Cumulative Cash Outlay)

the baseline VOR case over the same time frame (1978-2005); specifically, more than $4.4 billion greater than VOR costs.

(2) The optimum transition period to any new system would be approximately 10 to 15 years. Transitions of under 10 years severely penalize the users. Those over 15 years result in increased government costs because of the extended period during which multiple systems must be operated and maintained.

(3) The low cost avionics users absorb a disproportionately large share of the increased user costs associated with replacement of the VOR by alternative system(s). For any system to be economically viable it must include an effective, low-cost receiver for the general aviation user.

(4) If the GPS avionics costs, as estimated herein, can be reduced approximately 50% (and VOR avionics costs do not decrease), the resulting combined FAA plus user cumulative (1978-2005) costs for VOR and GPS will be comparable.

(5) If GPS is adopted in 1985 and GPS avionics costs do not drop appreciably (as noted above), the civil aviation community is better served (from an economic standpoint) if VOR is operated in conjunction with GPS. The additional FAA costs of approximately $1.2 billion required to operate the VOR system from 1995 through 2005 are more than compensated for by user savings of $2.9 billion.

(6) With the exception of the second generation VOR, early transitions to system alternatives do not appear to be cost effective in present value dollars. However, no conclusive trend is apparent when using undiscounted cash outlay totals.

(7) The alternative that appears to offer the lowest post-transition FAA plus NAS user annual recurring costs is Loran-C. However, when implementation and transition costs are included, second generation VOR is less costly. The implication, however, still exists that based upon its low post-transition recurring costs Loran-C <u>might</u> be a viable successor to VOR <u>if</u> it is viewed as a "permanent" replacement. Under this condition, transition to any other system, such as a satellite system, would be precluded until well into the next century.

(8) The implementation of second generation VOR appears to be cost justified, independent of the outcome of any eventual decision on a VOR replacement system.

(9) Individual systems, such as differential Omega <u>might</u> be justified for regional implementation (e.g., Alaska, Alaska off-shore) but the economic impact of such implementations is not clear cut and would depend heavily upon transition strategy, timing and national decisions (such as a potential decision to transition ultimately to a new "standard" worldwide system).

This report has presented an analysis of the cost impact of major air navigation alternatives upon the United States civil aviation community. In doing so it assumed the technical and operational feasibility of the systems addressed. Future efforts in the technical and operational areas may obviously impact costs. To this end it is apparent that while this study represents a required step in any decision making process, a substantial amount of future analysis of technical, operational, international, and economic factors will still be required.

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NOMENCLATURE

ADF	Automatic Direction Finder
CCZ	Coastal Confluence Zone
CONUS	Continental United States
COTR	Contracting Officer's Technical Representative
*DME	Distance Measuring Equipment
DOD	Department of Defense
FAA	Federal Aviation Administration
GA	General Aviation
ICAO	International Civil Aviation Organization
INS	Inertial Navigation System
L	Avionics Lifetime in Years
LF	Low Frequency
NA	Not Applicable
NAS	National Airspace System
NSE	Navigation System Evaluator (Life Cycle Cost Model)
O&M	Operating and Maintenance
OMB	Office of Management and Budget
R&D	Research and Development
RAANS	Requirements Analysis of Air Navigation Systems (i.e., the study described in this report)
RNAV	Area Navigation
RST	RAANS Support Team
SCI (Vt)	Systems Control, Inc. (Vt)
S/N	Signal to Noise
TACAN	Tactical Air Navigation
VLF	Very Low Frequency
*VOR	VHF Omnidirectional Radio Range
*VORTAC	VOR Co-located with a TACAN

*For the purpose of this report, no distinction is made after Section 1.1.2 between VOR/DME and VORTAC. Any reference to VOR type ground equipment is meant to include all VOR/DME and VORTAC facilities present in the NAS.

I. INTRODUCTION

1.1 BACKGROUND

The Federal Aviation Administration (FAA) in the role of manager of the National Airspace System (NAS) provides the systems and facilities to meet user requirements. These systems and facilities consist of three major subsystems:

(1) air navigation,
(2) communications, and
(3) surveillance.

The air navigation system provides the route structure and associated position information necessary for aircraft operation throughout the NAS. The communications and surveillance systems then provide the necessary tools to aid the controllers in insuring safe and efficient aircraft operation within the NAS and to maintain separation standards between aircraft. In meeting its NAS managerial obligations, the FAA must continually assess alternatives that could either enhance the performance of the NAS and/or provide more cost-effective methods of operation.

At the present time, navigation information for civil aircraft operating within the continental United States (CONUS) and portions of Alaska is provided primarily by the VOR/DME system. The VOR/DME has been the primary short-range civil navigation system throughout the United States for a number of years. It has been designated the ICAO standard through at least 1985.

1.1.1 Objectives

The FAA in fulfilling its responsibility to consider potential improvements to the NAS, in the post-1985 time frame, has initiated a number of activities including the study described in this report. This study was designed to develop a navigation system life cycle

cost computer model which would allow the FAA to ascertain the economic impact upon the aviation community of postulated alternative navigation system scenarios. Further, this model was to be exercised using the "best" system and avionics cost estimates currently available, to predict the economic impact on NAS users and the FAA, for each technically viable alternative. These alternatives were identified in a companion study, Ref. 1, which developed civil air navigation requirements for the CONUS, Alaska, CONUS off-shore, Alaska off-shore and Oceanic operating regions. It then "tested" each of the alternatives (described in Section 1.1.2) to ascertain which systems in each region could satisfy the established civil air navigation requirements.

It was not an objective of the study described in this report to "rank" or to identify a "preferred" navigation system, nor to address non-civil aviation applications. However, it is hoped that the parametric data developed and presented herein will define relevant cost sensitivities and thereby provide the information needed by various elements of the navigation community in formulating plans relative to the options available. This information is also expected to provide a useful data base for the system selection decision makers.

1.1.2 Navigation Systems Examined

The navigation systems addressed in this study consisted of the current systems (VOR/DME and self-contained) and their potential replacement alternatives (Omega, differential Omega, Loran-C and Global Positioning System — GPS).

The systems that currently provide the basic guidance for enroute air navigation in the U.S. are VHF Omnidirectional Range (VOR) and Distance Measuring Equipment (DME). Information provided to the aircraft pilot by VOR is azimuth relative to the VOR ground station. DME provides a measurement of distance from the aircraft to the DME ground station. In most cases, VOR and DME

are co-located as a VOR/DME facility. TACAN (Tactical Air Navigation) provides both azimuth and distance information and is used primarily by military aircraft. When TACAN is co-located with VOR it is a VORTAC facility.* DME and the distance measuring function of TACAN are the same. The VOR/DME is a short-range system and does not have the capability to provide long-range coverage over oceanic regions. In addition, it may not be cost effective to provide VOR/DME coverage over the entire state of Alaska and over the off-shore regions of either the CONUS or Alaska. There are now approximately 950 VOR/DME and VORTAC stations in the NAS.

Currently, navigation over oceanic regions is typically provided by inertial navigation systems (INS), doppler radar and Omega; the latter being one of the alternative systems that will be evaluated for potential civil air navigation applications in other regions. In addition to Omega there are several other navigation systems, including differential Omega, Loran-C and Global Positioning System (GPS), that may be viable alternatives to either replace or supplement the prevailing civil air navigation systems.

Omega is an international very low frequency (VLF) radio navigation system dedicated to providing a global all-weather navigation and positioning capability of moderate accuracy. It operates in the internationally allocated frequency band between 10 and 14 kHz. At these frequencies, the earth's surface and the ionosphere act as a wave guide which allows the signals to propagate over long distances with relatively low attenuation and relatively high stability. Omega is designed to provide all-weather navigational service throughout the world with a transmitting complex of eight stations. The permanent stations transmit at 10 KW which is sufficient power at these frequencies to propagate a signal half way around the world and farther under certain conditions.

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* For the purposes of this report, after this section no distinction is made between VOR/DME and VORTAC. Any reference to VOR type ground equipment is meant to include all VOR/DME and VORTAC facilities present in the NAS.

The Omega Navigation System Operations Detail (ONSOD) of the U.S. Coast Guard is the responsible agency for the United States.

Differential Omega is a system concept which has been evaluated for reducing the position errors of standard Omega. The differential ground unit consists of a monitor receiver at a fixed, known location, and an uplink transmitter. The monitor receiver measures the actual Omega signal phases, and compares them with the nominal phase characteristics for the known monitor location. The differences between the actual and nominal phase measurements are used to generate correction data, which are uplinked to Differential Omega users in the service area. The differential Omega receiver decodes the correction data from the uplink and uses these to correct the Omega signals measured by the user Omega equipment. For reasonable ranges, less than 200 nm, there exists good correlation between the Omega signal errors measured by the monitor station and by the user equipment; hence, Differential Omega can provide a substantial accuracy enhancement. This accuracy enhancement is based on having reasonably good standard Omega coverage over the region of interest. Differential Omega can reduce the errors resulting from propagation phase prediction errors, but cannot correct for poor phase measurements (due to poor S/N ratios) or poor Omega station/receiver geometry.

Loran-C is a low frequency (LF) hyperbolic radio navigation system developed by the Department of Defense during the 1950s to meet operational military requirements. The first Loran-C chain, located along the U.S. East Coast, became operational during 1959-1960. Today, there are nine chains operated by the U.S. Coast Guard throughout the world, with a total of 12 expected by 1980. Currently, there are four chains, with a total of 15 stations, providing coverage over CONUS, Alaska, and Offshore. These stations are part of the approved Loran-C network to meet the Coastal Confluence Zone (CCZ) maritime requirement. By 1980, the approved CCZ Loran-C network will be completed with the addition of five more stations for a total of 20 stations. The addition of five

more stations to provide midcontinent CONUS coverage has been proposed but not approved. (Detailed descriptions of the Omega, differential Omega and Loran-C systems including an evaluation of their capabilities relative to civil air navigation requirements are presented in Ref. 1.)

The Global Positioning System (GPS) is a Department of Defense (DOD) program to provide very precise position information for a wide variety of military users, with the possibility of simultaneously providing civil air navigation information. GPS is divided into three segments*: A space segment, control segment, and user equipment segment. The operational space segment consists of three planes of satellites in circular 10,900 nautical mile orbits. Each plane would contain eight satellites. This deployment ensures that at least six satellites are continuously in view from any point on earth. Each satellite will broadcast a signal containing information as to its position. The control segment will consist of ground stations necessary to track the satellites, monitor the system operation, and periodically provide corrections to the navigation and time signals. The user segment will consist of the equipment necessary to convert the satellite signals into useful navigation information. By receiving signals from four satellites, the user can calculate his precise time, three-dimensional position, and three-dimensional velocity.

1.2 PROGRAM PLAN

The activity described herein was implemented in three phases. As shown in Figure 1.1, the development or first phase consisted of defining the characteristics of each of the navigation system alternatives and simultaneously developing a navigation system life-cycle cost (LCC) model. These system descriptors and the LCC model were used in combination with plausible implementation scenarios defined during the analysis phase to derive the resulting economic evaluation criteria. Finally, these results, supplemented

*GPS system description taken from Ref. 2.

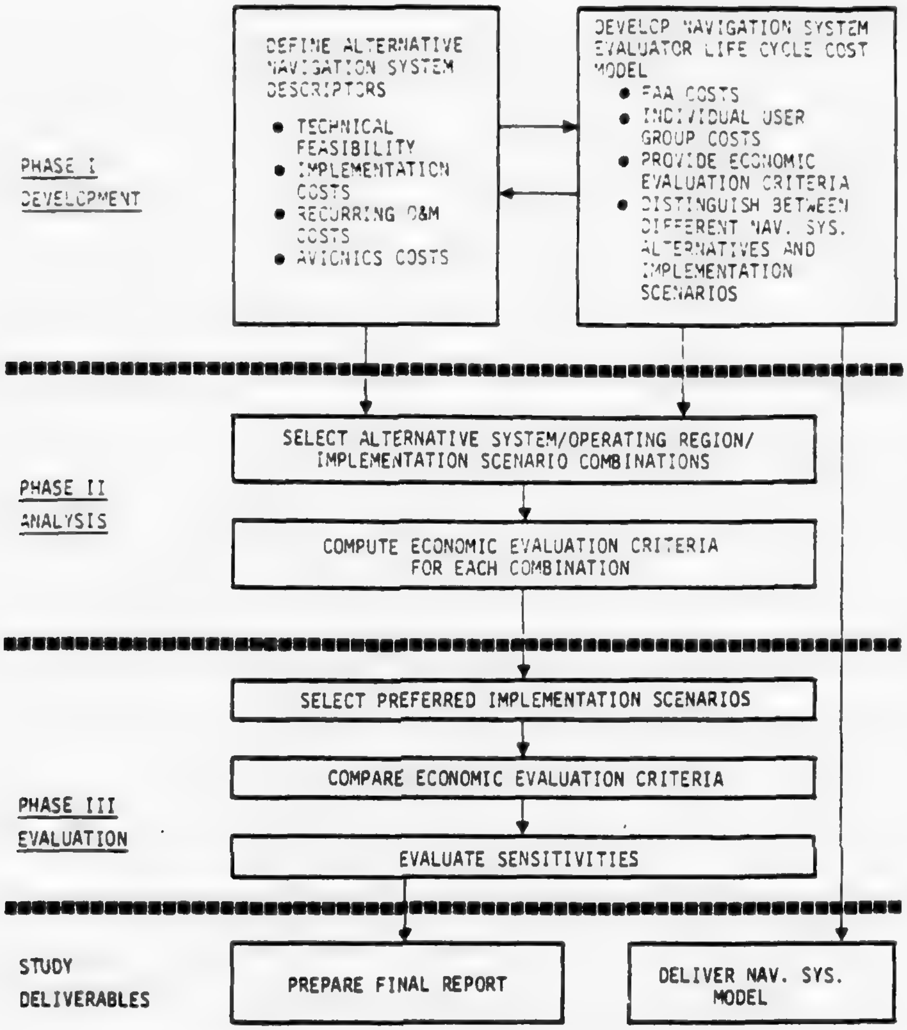


Figure 1.1 RAANS Program Plan Overview

by sensitivity analysis (perturbations of a number of significant system descriptors and/or analysis methods), were compared and documented in the evaluation phase. LCC model demonstration and documentation were also completed during this last phase.

1.3 REPORT FORMAT

The results of this study are published in two volumes. Volume I is divided into six sections focusing on the methodology, input data development and results. The approach by which the economic

evaluation criteria are quantified for each navigation system alternative is described in Section II. The guidelines and ground rules under which the results of this study were produced are compiled and listed in one place in Section III. The reader is encouraged to review and develop and understanding of these "qualifiers" before using and possibly misinterpreting this study's results.

Section IV describes how the navigation systems were characterized with particular emphasis on the FAA's implementation and operating costs and the cost of avionics which would be incurred by the NAS users. Plausible implementation scenarios developed for each alternative system are identified and discussed in Section V.

Finally, Section VI presents the resulting economic evaluation criteria associated with each navigation system alternative.

Volume II contains appendices amplifying the FAA and user cost estimation methodology, detailing the derivation of navigation system and avionics cost inputs and providing backup study results.

II. APPROACH

Projected FAA and NAS user costs resulting from postulated transitions to alternative navigation system(s) were quantified through the use of a navigation system evaluator (NSE) life cycle cost model developed as part of this study. The NSE software and user's guide will be documented in Ref. 3. The cost derivation concepts, method of application logic and limitations, i.e., the cost derivation approach, much of which is incorporated into the NSE model, are described in three subsections addressing FAA costs, other government costs and NAS user costs, respectively. The details of the study methodology are provided in Appendix A of Volume II.

The approach used in quantifying FAA and NAS user costs is illustrated in Figure 2.1. The ensuing discussion is keyed to the flow of that figure.

2.1 FAA COSTS

The FAA costs consist of two elements: (1) the costs to bring the specified navigation system or systems up to an operational state, i.e., implementation costs, and (2) annual recurring costs. The FAA implementation costs were determined for each viable navigation system alternative-operating region(s) combination (Section 4.1). The specified implementation scenario then dictated not only what system-region combinations were to be considered, but also indicated over what period those systems were to be implemented and the annual distribution of the total implementation costs expended during that period.

The annual recurring costs to be incurred by the FAA once the system is operational are determined (described in Section 4.1) as a function of navigation system type-operating region(s) combination. During the alternative system implementation period the annual recurring costs are increased in proportion to the system

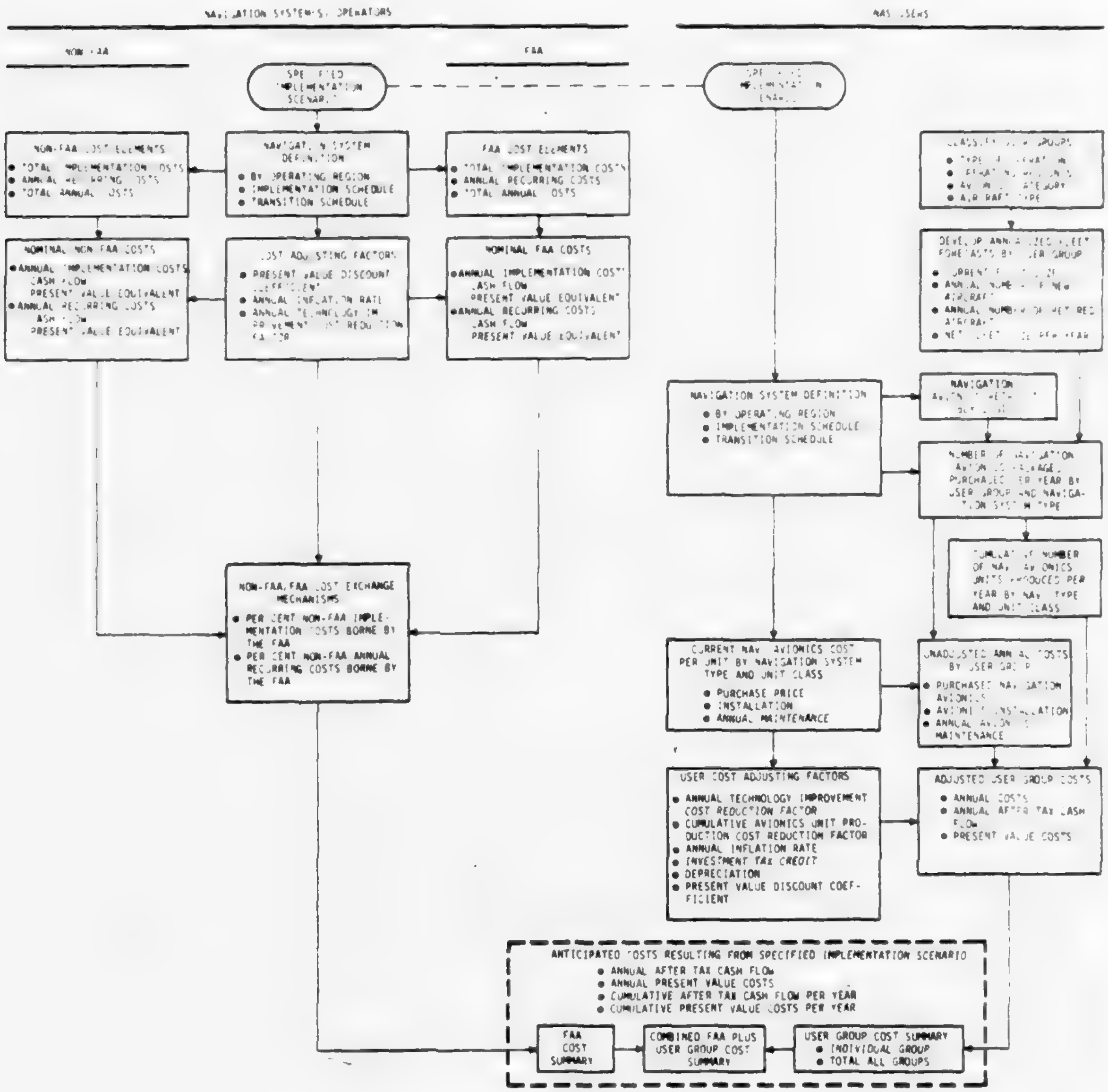


Figure 2.1 Overview of RAANS Study

hardware cost expended through the year of interest relative to the total implementation hardware costs.

Time (year) related technology factors (nominally zero) were then applied to the hardware related component of the FAA's annual cost. Other cost adjustment factors, i.e., inflation and a present value conversion factor, were applied to all FAA costs. When these costs are properly aggregated, annual and cumulative to date cash flow and present value costs result.

2.2 OTHER GOVERNMENT COSTS

Similar procedures were applied to determine navigation system related costs incurred by other government (non-FAA) agencies, such as Loran-C costs absorbed by the United States Coast Guard. The NSE model has the capability of transferring any proportion of these normally non-FAA implementation and/or recurring costs into the FAA category.

2.3 NAS USER COSTS

Costs incurred by the NAS users as a result of a specified navigation system implementation scenario were limited to those costs related to enroute navigation avionics. To facilitate an an accurate determination of these costs and to provide the ability to differentiate between subtle implementation scenario variations, the NAS users were divided into groups distinguished by four characteristics:

(1) Type of Operation (4)

- Air Carrier
- Air Taxi (including commuter)
- Executive/Business
- Personal/Other

(2) Operating Region(s) (8)

- CONUS
- CONUS and Alaska
- CONUS and CONUS Off-shore
- CONUS and Oceanic

(2) Operating Regions(s) (8) (Continued)

- CONUS, Alaska and Oceanic
- CONUS, Alaska, CONUS Off-shore and Alaska Off-shore
- Alaska
- Alaska and Alaska Off-shore

(3) Avionics Category (10)

- Minimum Cost, Least Sophisticated
-
-
- Increasing Cost, Sophistication and Reliability
-
-
-
-
-
- Maximum Cost, Most Sophisticated

(4) Aircraft Type (4)

- 3-4 Engine Jet
- 1-2 Engine Jet
- Prop
- Helicopter

Of the 1,280 possible combinations of these characteristics, 98 were identified that were both plausible (e.g., helicopters operating in the trans-oceanic region were eliminated) and had reasonable aircraft populations (e.g., groups with less than four aircraft were merged into other groups).

Fleet population projections were developed for each of the 98 user groups from 1977 through the year 2000, based primarily on information obtained from Ref. 4, which in turn utilized FAA forecasts. These projections consisted of annual number of new, retired and net aircraft.

Based upon the specified transition schedule (Section V), avionics purchase logic (Volume II, Appendix A) and avionics package composition (Section IV), the number of avionics units sold in each year were computed. Technology and production base cost reduction factors were then applied together with inflation factors to obtain annualized avionics costs. Conversion of yearly user costs to annual after tax cash outlay was then accomplished

by applying an investment tax credit during the year of purchase and depreciation of previously purchased avionics to the air carrier, air taxi and business/executive user groups. The resulting annual after tax cash outlays were then converted to present value equivalents for each of the 98 user groups through the application of an annual discount factor.

The individual user group annual after tax cash outlay and equivalent present value costs were processed to produce cumulative annual totals. Each of these four economic evaluation criteria (annual after tax cash outlay, cumulative to-date after tax cash outlay, annual present value costs and cumulative to-date present value costs) were then aggregated across all user groups to produce a single representative user group cost summary.

Finally, corresponding economic evaluation criteria from the FAA and user group cost summaries were totaled to produce the combined FAA plus user group annual cost summary required for each alternative navigation system and implementation scenario combination examined.

Descriptions of the methodology associated with the significant elements of the approach are presented in Appendix A. Specifically, implementation and operating cost data base format, implementation scenario inputs, major processing elements and cost output options are described relative to FAA cost derivations. NAS user cost items include user group definition and fleet forecasts, enroute navigation avionics age distribution and lifetime estimates, accelerated avionics retrofit rates, avionics purchase rate logic, production base cost reduction factors and technology improvement cost reduction factors.

III. STUDY GUIDELINES AND GROUND RULES

This RAANS study of advanced navigation systems and their economic impacts projected to and beyond the year 2000 required the establishment of a number of guidelines and/or ground rules. While most of these are alluded to elsewhere in this report, it was considered appropriate to provide, in one place, a comprehensive list of the guidelines and ground rules applied in this study. The reader is encouraged to review and consider this list, so as to preclude misinterpreting the study results presented in Section VI.

FAA Costs

- Navigation system operation support
  - FAA incurs 100% of the implementation and O&M costs associated with the VOR/DME system
  - FAA incurs only that portion of the alternative system implementation and/or O&M costs required to make that system acceptable for civil aviation use
  - FAA costs associated with "self-contained" system, i.e., INS, were set at zero.
- Total system implementation costs incurred by the FAA increased from zero to full value over the designated implementation period and set at full value thereafter, as long as the system is operating for civil aviation.
- No residual value "credit" was given for equipment when a system was decommissioned.
- To be consistent with the OMB's "Proposed Federal Radio Navigation System Plan" a 7% annual inflation rate was applied to all FAA costs.
- A 10% annual discount coefficient was used for present value computations.

User Costs

- Costs were limited to those related to enroute navigation avionics
  - Glideslope and marker beacon component costs have been deleted.

- With the exception of INS, annual maintenance costs were not included since they are believed to be comparable for similar quality avionics components of all systems

  — A $9,000 per year additional increment was used for INS

- Installation costs including antenna (purchase and installation) and "aircraft tuning," if required for a given system, were not included because of the unavailability of credible data.

- All aircraft considered and retained through system transitions have at least VOR or equivalent enroute navigation capability. Aircraft without this capability were not included in this analysis.

- A range of avionics quality was created for both current and proposed alternative systems.

  — Four "lines" (Grades A, B, C and D) of components (representing the spectrum from rather elementary to highly sophisticated units) were developed for each system
  — Users modeled to maintain the same "quality" systems when transitioning from initial to alternative system avionics, independent of cost impact.

- Additional user benefits such as IFR approach capability which may be provided by alternative systems were not utilized to defer other user costs.

- Avionics cost reduction factors (see Volume II, Appendix A).

  — Improved technology cost reduction factor of 5.1% per annum was applied to all avionics costs
  — Production base cost reduction factor was applied to all avionics components up to a cumulative production of 20,000 units
  — An investment tax credit of 10% (Ref. 5) was applied to avionics purchase cost for air carrier, air taxi and executive/business type of operations. This factor was included to more accurately reflect the actual dollar impact on individual user groups.
  — A straight line, 7 year depreciation with no residual value was applied to avionics purchase cost for air carrier, air taxi and executive/business type of operations
  — A 52% tax bracket was used in computing the after tax cash flow for each of the two preceding items.

- A 7% annual inflation rate was applied to all user costs (again to be consistent with OMB's "Proposed Federal Radio System Plan").

- A 10% annual discount coefficient was used in computing present value cost equivalents.

- Enroute navigation lifetimes were established from the SCI (Vt) survey and subsequently used in retrofit logic (details are presented in Volume II, Appendix A)

  — Air carrier - 14 years
  — Air taxi, executive/business, personal/other - 11 years.

Navigation System Types Considered

- Current systems

  — VOR in CONUS and Alaska
  Self-contained (INS and Other, such as Doppler radar) in oceanic and off-shore regions

  NOTE: The baseline case substituted Omega for self-contained to avoid multiple transitions and simplify NSE model logic since it was presumed that once Omega was approved for oceanic navigation, users would voluntarily transition to Omega because of its lower costs relative to INS.

- Alternative systems which satisfy civil air navigation requirements in designated operating regions [Ref. 1]

  — Loran-C (all regions but oceanic)
  — Omega (oceanic, Alaska and Alaska off-shore)
  — Differential Omega (Alaska and Alaska off-shore)
  GPS (all regions).

User Group Characterization

- NAS users were divided into 98 user groups through the use of the following characteristics

  — Type of operation (4)
  — Avionics category (10)
  — Operating regions (8)
  — Type of aircraft (4)

Navigation System Evaluator (NSE) Model Constraints

- A transition period cannot be in progress in the base year (1978).

- Multiple transitions are not possible.

- User/FAA annual recurring costs are constant (in constant dollars) for each navigation system.

- Aircraft cannot upgrade (change avionics categories).

- No accounting can be made at end of run to determine residual values.

- Oldest avionics units retire first; next oldest units transition first.

- Avionics lifetime is deterministic.

- Ages of enroute navigation avionics components on a given aircraft in base year are the same; i.e., all equipment on a given existing aircraft expire simultaneously.

- Aircraft fleet projections are frozen at the year 2000. However, the NSE model may be run beyond the year 2000.

- The number of transitioning aircraft is based on a "base" population, i.e., those aircraft that both enter and survive the transition period.

- Occasionally (when long transitions are run) avionics units are allowed to "exceed" lifetime.

- All aircraft in a given user group are constrained to the same purchase strategy.

- FAA recurring costs increase from zero to full value according to hardware implementation rate (except for those systems which are in operation initially, i.e., VOR/self-contained).

- VOR and self-contained systems are operational initially. Alternative systems (Omega, differential Omega, Loran-C and GPS) must be "implemented" to become operational.

- Incremental implementation expenses can be spent on improving the VOR and self-contained systems (1,2) while they are operational. The remaining alternative systems (3-6) must be fully implemented before becoming operational.

NSE Model Utilization

- Current equipment for off-shore and oceanic users, i.e., self-contained, was assumed to be Omega.

- For case where Alaska and Alaska off-shore users transitioned to differential Omega, prior Omega sales had to be artificially changed. NSE model works with system

"indices" and cannot determine that two systems with different indices (i.e., self-contained Omega and differential Omega) have anything in common.

Data Quantification and Study Approach Establishment Procedure

Modeling the projected costs associated with alternative navigation systems whose evolutionary state runs the gambit from paper designs to fully operational systems, as well as user reactions to specified scenarios through and beyond the year 2000, required a great deal of care so as not to bias the results. The data used in this study was, in the judgment of the contractor and cognizant FAA personnel the "best available" at the date of its use. However, it was recognized that many of the study inputs would change in time as the candidate systems evolve. For this reason, the Navigation System Evaluator (NSE) model was a deliverable to the FAA under the RAANS effort. Access to the NSE will permit the FAA to update the study results if and when there are substantive changes in this study's input values.

A procedure was developed to consider the opinions of many knowledgeable individuals and organizations prior to finalizing the RAANS data base and study approach. An overview of the procedure is illustrated in Figure 3.1 and described below. Documents describing each of the alternative navigation systems were reviewed and appropriate data extracted. The contractor conducted a survey of FAA certificated navigation avionics repair stations to estimate avionics age and lifetime factors. SCI (Vt)'s in-house experience gained in part from the study of the alternative navigation systems relative to their ability to satisfy civil aviation requirements [Ref. 1], as the FAA's support contractor for area navigation and many other relevant studies, was used in not only developing data but in assessing the potential credibility of data obtained from many different sources. Mr. G.F. Quinby was used as a RAANS consultant, primarily to provide inputs with respect to avionics costs. Finally, many conversations were held with aviation community representatives to either obtain specific

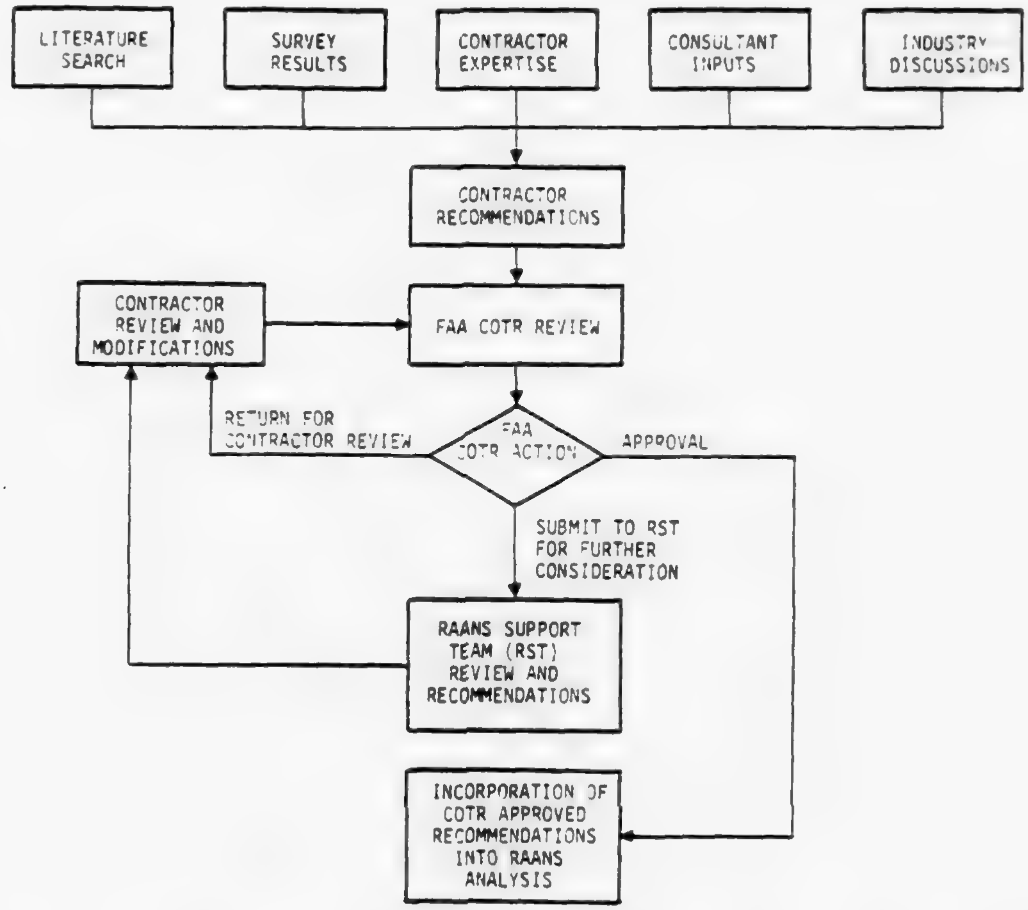


Figure 3.1 Overview of RAANS Data/Approach Establishment Procedure (Applicable to Navigation System and Avionics Cost and Study Guidelines and Ground Rules)

data or to confirm the validity of a particular part of the RAANS approach.

These information sources were used throughout the RAANS study to produce a series of recommendations which were submitted to the FAA COTR. Depending on the anticipated impact on the study results, the confidence level associated with a given recommendation, the potential for controversy and other factors, the COTR could either:

(1) approve the recommendation;

(2) return it to the contractor for further analysis; or

(3) submit it to the RAANS Support Team (RST) for review.

The RST was nominally composed of SCI (Vt) representatives, the FAA COTR and personnel from the FAA Systems Research and Development Service (Enroute Navigation Branch), FAA Office of Systems Engineering Management (Technical Programs Division), and FAA Office of Aviation System Plans (Planning Requirements Branch). In addition to reviewing contractor recommendations, the RST directly developed many cost inputs used in the RAANS study. Ultimately a single set of all required inputs was approved for use in the RAANS analysis.

IV. NAVIGATION SYSTEM CHARACTERIZATION

The cost components of the RAANS input data base, which were used to characterize each navigation system, are described and listed in this section. These cost components are divided into two groups: (1) those associated with the implementation and operation of the system (which are used to compute FAA costs), and (2) those related to the cost of a given system's avionics (which are used to estimate a given scenario's cost impact on the NAS users).

4.1 NAVIGATION SYSTEM COSTS

The navigation system costs used in the RAANS study are listed in Table 4.1. The top half of the chart presents the costs associated with implementing a given system, i.e., bring it up to an operational state or, in the case of the VOR, converting the current system into either an "upgraded VOR" or a "second generation VOR." These are typically one time costs spread over the implementation period.

The lower portion of Table 4.1 presents the total annual recurring costs anticipated to be required for the day-to-day operation of the designated system.

The left hand side of the table contains the remaining implementation and recurring cost estimates for agencies other than the FAA which are either operating or are planning to implement and/or operate navigation system(s). The USCG (Loran-C and Omega) and DOD (GPS) are examples of the non-FAA agencies operating or planning to operate navigation systems.

The right hand side of the chart contains estimates of FAA implementation and recurring costs for each of the systems evaluated in the RAANS study. The FAA portion of the Loran-C, Omega, differential Omega and GPS systems reflect only the additional

Table 4.1

Anticipated Navigation System Costs

(Millions of 1977 Dollars)

OPERATING REGIONS	COSTS TO BE INCURRED BY NON-FAA SPONSORING AGENCIES							COSTS TO BE INCURRED BY THE FAA TO SATISFY CIVIL AIR ENROUTE NAVIGATION REQUIREMENTS							
	CURRENT SYSTEMS			ALTERNATIVE SYSTEMS				CURRENT SYSTEMS			ALTERNATIVE SYSTEMS				
	VOR/DME UPGRADED	VOR/DME 2ND GEN.	SELF-CONTAINED	LORAN-C	OMEGA	DIFF. OMEGA	GPS	VOR/DME UPGRADED	VOR/DME 2ND GEN.	SELF-CONTAINED	LORAN-C	OMEGA	DIFF. OMEGA	GPS	
REGION INDEPENDENT	*	*	*	Incorp. In CONUS O.S. & AK O.S.	19.10	19.10	763.00	3.10	3.20	0	5.50	4.10	7.20	7.50	NAVIGATION SYSTEM IMPLEMENTATION COSTS $M
CONUS	*	*	*	*	*	*	*	54.9	108.50	0	63.68	*	*	16.00	
ALASKA	*	*	*	*	*	*	*	22.5	25.00	0	10.53	1.70	5.28	1.70	
CONUS OFF-SHORE	*	*	*	66.00	*	*	*	*	*	0	66.73	3.90	10.30	3.90	
ALASKA OFF-SHORE	*	*	*	26.40	*	*	*	*	*	0	9.60	0.60	1.76	0.60	
OCEANIC	*	*	*	*	*	*	*	*	*	0	*	0.60	*	0.60	
REGION INDEPENDENT	*	*	*	Incorp. In CONUS O.S. & AK O.S.	4.54	4.54	127.00	1.10	1.10	0	1.10	1.10	1.10	1.10	NAVIGATION SYSTEM ANNUAL RECURRING COSTS $M/YR
CONUS	*	*	*	*	*	*	*	32.50	19.70	0	2.09	*	*	0.35	
ALASKA	*	*	*	*	*	*	*	2.60	1.54	0	0.32	0.07	0.88	0.07	
CONUS OFF-SHORE	*	*	*	3.10	*	*	*	*	*	0	1.98	0.14	1.13	0.14	
ALASKA OFF-SHORE	*	*	*	2.38	*	*	*	*	*	0	0.27	0.09	0.36	0.09	
OCEANIC	*	*	*	*	*	*	*	*	*	0	*	0.11	*	0.11	

*Not Applicable

incremental costs required to make those systems compatible with civil aviation requirements. The distinction between VOR/DME and second generation VOR/DME is that the second generation system includes features such as Remote Maintenance Monitoring which will allow significant reduction in maintenance costs; while upgraded VOR/DME is merely a solid state replacement for existing vacuum tube equipment.

The left hand column of Table 4.1 further subdivides the implementation and recurring costs by each of the five operating regions plus an "area independent" region. This latter "region" was included to account for those constant costs which are incurred when a system is either implemented or operated in at least one region, i.e., "headquarter costs." For example, if a system was implemented only in the CONUS region, the total costs would be the sum of the CONUS plus area independent cost components.

The costs shown in Table 4.1 are totals of cost contributing components. Implementation costs were divided into hardware, R&D and training. O&M, spares replacement, staff, charting and other cost categories contribute to the annual recurring cost totals shown. A breakdown into these components, when feasible, plus a description of the source and/or derivation of these costs, is presented in Appendix B of Volume II.

4.2 ENROUTE NAVIGATION AVIONICS CHARACTERIZATION AND ASSOCIATED COST ESTIMATES

4.2.1 RAANS Avionics Characterization

To produce credible NAS user cost impacts, it was recognized that a range of avionics capabilities, sophistication, reliability and associated costs would have to be incorporated into the RAANS study approach for each candidate navigation system. This was accomplished by creating ten unique avionics categories as described in Table 4.2. These categories provided a portion of the grouping criteria which were used to distinguish the 98 RAANS user groups.

Table 4.2
Characterization of RAANS Study Avionics Categories

CATEGORY NUMBER	DESCRIPTION
1	Minimal Enroute Navigation Avionics Used Primarily by Non-IFR Pilots
2	Low Cost Enroute Navigation Avionics for General Aviation Users
3	Intermediate Cost Enroute Navigation Avionics for General Aviation Users
4	High Cost Enroute Navigation Avionics for General Aviation Users
5	Intermediate Cost Enroute Navigation Avionics, Including Area Navigation Equipment, for General Aviation Users
6	High Cost Enroute Navigation Avionics, Including Area Navigation Equipment, for General Aviation Users
7	Air Carrier Type Enroute Navigation Avionics with Non-INS, if Required for Over Water Navigation
8	Air Carrier Type Enroute Navigation Avionics with Dual INS, if Required for Over Water Navigation
9	Air Carrier Type Enroute Navigation Avionics with Triple INS, if Required for Over Water Navigation
10	Air Carrier Type Enroute Navigation Avionics Including Area Navigation Equipment

Once a user group was placed in an avionics category, the enroute navigation package that that group would purchase, for a given system type, was predetermined. The composition of each category's avionics package, by type of navigation system, is defined in Table 4.3. The letter code (A, B, C or D) used in "grading" specific components reflects the available or, in the case of the alternative systems, anticipated range of sophistication and cost. The (A) grade represents low cost and unsophisticated versions* of the designated component, e.g., VOR.

*The (A) and (D) components were selected to represent the range of low and high cost components, respectively, not the single lowest or highest cost components available.

Table 4.3

Composition of RAANS Avionics Packages
(Number of Avionics Components Per RAANS Category Package)

NAVIGATION SYSTEM TYPE	ENROUTE NAVIGATION AVIONICS COMPONENTS		RAANS AVIONICS CATEGORY									
			1	2	3	4	5	6	7	8	9	10
CURRENT SYSTEMS	TYPE	GRADE										
VOR	VOR	(A)	1	2								
	VOR	(B)			2		2					
	VOR	(C)				2		2				
	VOR	(D)							2	2	2	2
	DME	(B)			1		1					
	DME	(C)				1		1				
	DME	(D)							2	2	2	2
	RNAV	(B)					1					
	RNAV	(C)						1				
	RNAV	(D)										1
SELF-CONTAINED*	INS									2	3	
	OTHER S.C.		1	1	1	1	1	1	2			2
ALTERNATIVE SYSTEMS												
LORAN-C	LORAN-C	(A)	1	2	1							
	LORAN-C	(B)			1	1	2					
	LORAN-C	(C)				1		2				
	LORAN-C	(D)							2	2	2	2
OMEGA	OMEGA	(A)	1	2	1							
	OMEGA	(B)			1	1	2					
	OMEGA	(C)				1		2				
	OMEGA	(D)							2	2	2	2
DIFFEREN-TIAL OMEGA	DIFF.OMEGA	(A)	1	2	1							
	DIFF.OMEGA	(B)			1	1	2					
	DIFF.OMEGA	(C)				1		2				
	DIFF.OMEGA	(D)							2	2	2	2
GPS	GPS	(A)	1	2	1							
	GPS	(B)			1	1	2					
	GPS	(C)				1		2				
	GPS	(D)							2	2	2	2

*Applicable only to users operating in oceanic and/or off-shore regions

A single (A) grade VOR makes up the total enroute navigation package assumed to be used by VFR pilots, i.e., avionics cateogry 1. The sophisticated, high cost air carrier type components are denoted by a (D) grade. Avionics category 9 (air carrier with triple INS) would, as indicated in Table 4.3, consist of dual VOR (D)'s and dual DME (D)'s. If the user group(s) in question

operated in either the oceanic or off-shore region(s), their avionic package would also contain triple INS self contained units. (Generally, in this study, Omega was used in place of self-contained, in which case, the avionics category 9 over water user was assumed to have dual Omega (D) units in place of triple INS.)

Avionics category 9 users who transition to alternative navigation systems would retrofit (or if considering a new aircraft, would initially equip) with dual (D) grade units of the designated alternative(s).

4.2.2 Avionics Costs

In order to implement this multiple avionics grade approach, it was necessary to establish a 1977 cost and the number of units produced to date estimate for each of the avionics components listed in Table 4.3. This was a somewhat subjective procedure with several iterations required between the contractor, the RAANS Support Team (RST), and the project COTR before the resulting set of cost and production data were deemed mutually acceptable.

The derivation procedure, data sources and supporting rationale which lead to the RAANS avionics component cost estimates are described in Volume II, Appendix B. This procedure included modifying costs of existing components so that precision landing functions were excluded, i.e., integral marker beacon and glideslope subsystems and their estimated cost contribution were deleted. Common use of equipments for enroute and non-precision approaches were assumed. The resulting component costs are illustrated in Figure 4.1.

The vertical bars depict the range of costs (on a logarithmic scale) for a given type of navigation system. The dotted lines trace the price fluctuation of specified avionic component grades (A-D) between the set of navigation systems.

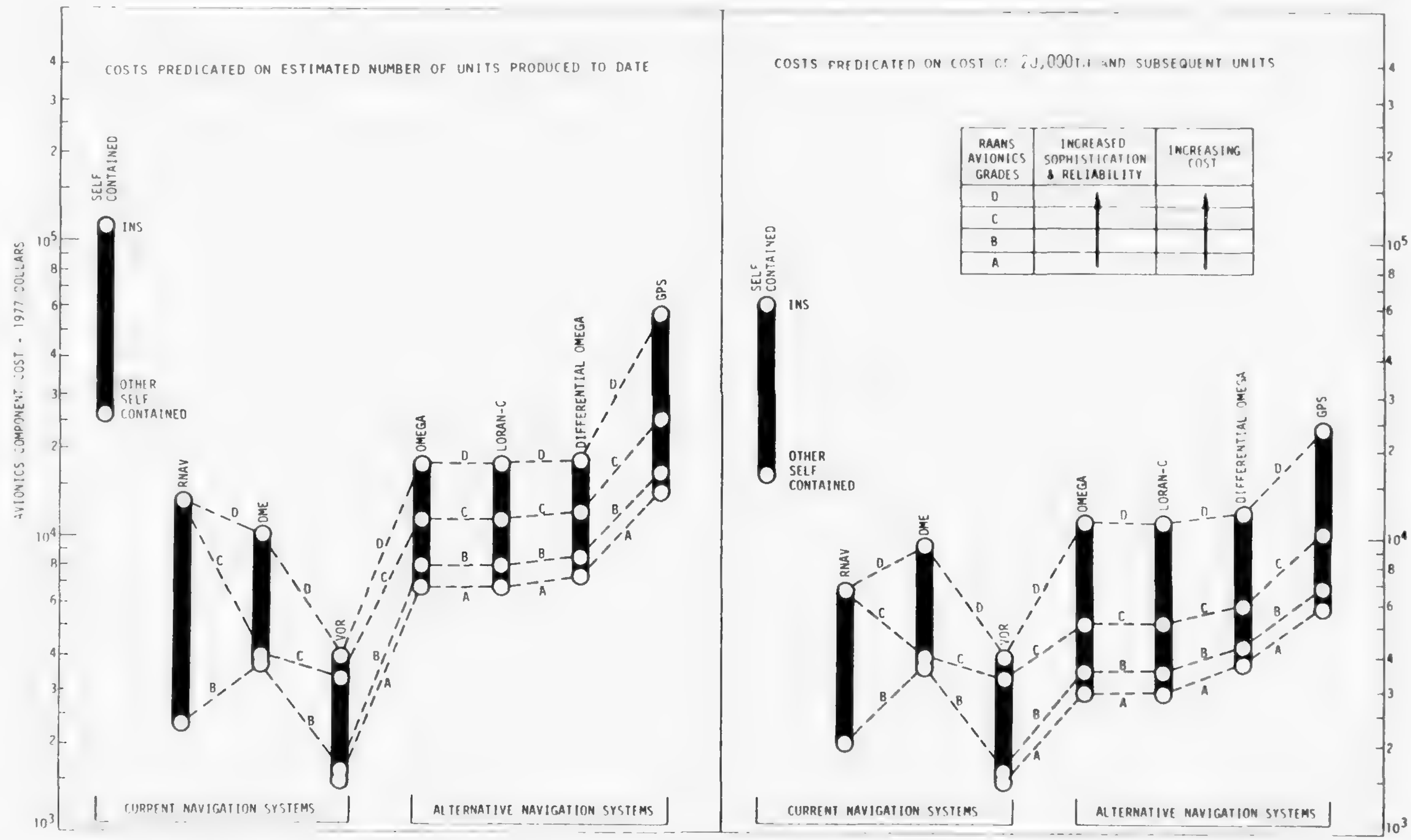


Figure 4.1 Avionics Component Cost Comparison by Navigation System and Type and RAANS Avionics Class (A, B, C, or D) 1977 Technology and Dollars

In addition to the costs predicted on the 1977 estimated number of units produced to date (left half of Figure 4.1), the prices based on achieving at least a 20,000 unit production base are illustrated on the right side of the figure. The 20,000th unit is equivalent to the lowest price that can be attained in the RAANS analysis due to production base related cost reductions (see Volume II, Appendix A, for details). Thus, depending on the number of units produced at the time of purchase, the cost to the user for a given component would lie somewhere between the two values shown in Figure 4.1 (additional cost adjustments include inflation at 7 per cent per year and technology improvement induced cost reductions at 5.1 per cent per year). Thus, those units which exceeded 20,000 units in 1977, such as all of the VOR's, maintained a constant price. Those units currently approaching only prototype production levels such as GPS are projected to realize a substantial drop in prices as production increases. The GPS unit prices are modeled to drop 60 per cent from their "current" values if 20,000 or more units of a given component grade are produced. The function used as a production base cost reduction factor is illustrated in Figure 4.2.

Using Figure 4.1 and the data from Table 4.3, which indicates how the A, B, C and D units are used to compose the 10 avionics suits, comparable costs for each of the 10 RAANS avionics category packages were developed and are displayed in Figure 4.3. These categories were initially numbered (Table 4.2) so as to generally reflect increasing costs. This is not the case in all instances; for example, when category 9 includes triple INS it has higher costs than category 10.

The specific values for the avionics component and package costs, by navigation system, are presented in Tables 4.4 and 4.5, respectively. The estimated number of similar units produced to date (1977), for the RAANS production base cost reduction factor computation, is also presented in Table 4.4.

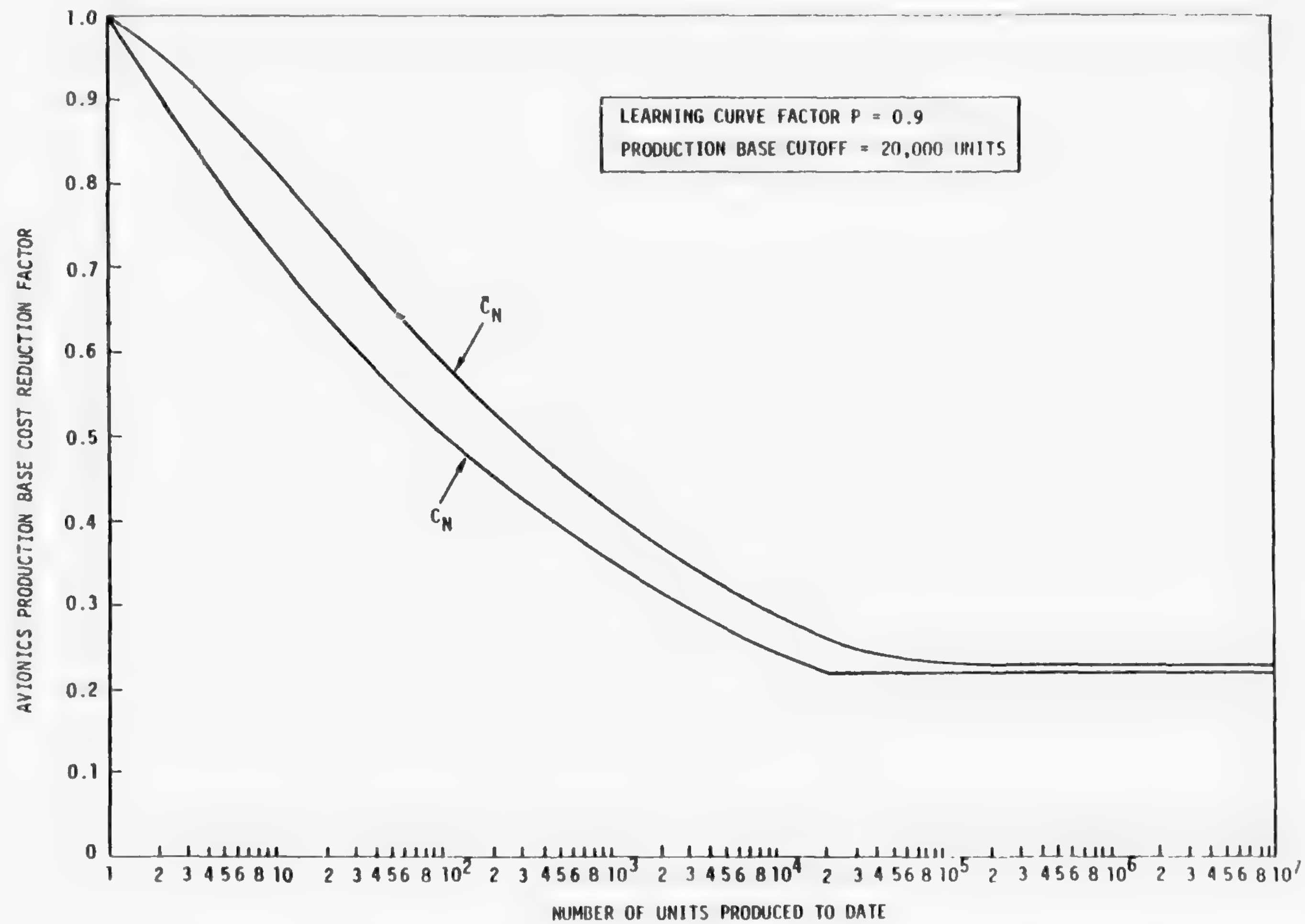


Figure 4.2 Production Base Cost Reduction Factors Relative to First Unit Price Cost of Nth Unit (C_N) and Average Unit Cost of First through Nth Unit ($\bar{C}_N$)

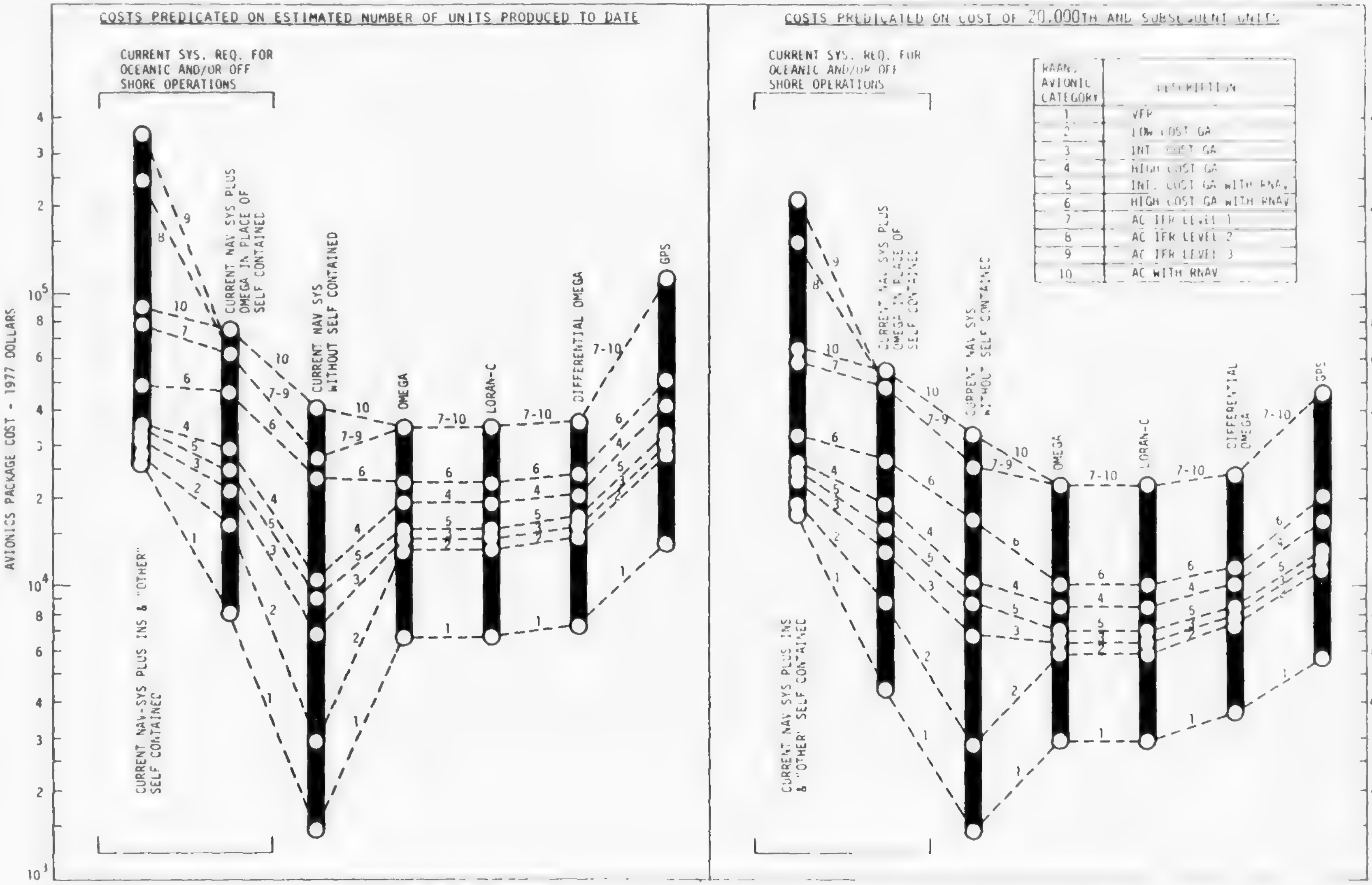


Figure 4.3 Avionics Package Cost Comparison by Navigation System Type and RAANS Avionics Category (1-10) 1977 Technology and Dollars

Table 4.4

RAANS Estimated Enroute Navigation Avionics Component Prices

NAVIGATION SYSTEM TYPE	AVIONICS COMPONENT DESCRIPTION BY RAANS GRADE	ESTIMATED NUMBER OF SIMILAR UNITS PRODUCED TO DATE	RAANS ADJUSTED 1977 PRICE PER UNIT	ESTIMATED+ RAANS PRICE OF 20,000 AND SUBSEQUENT UNITS
VOR	VOR (A)	503,479	$ 1,495	$ 1,495
	VOR (B)	211,565	1,604	1,604
	VOR (C)	96,587	3,318	3,318
	VOR (D)	32,330	3,919	3,919
	DME (A)	0	NA	NA
	DME (B)	43,558	$ 3,695	$ 3,695
	DME (C)	19,886	3,950	3,947
	DME (D)	13,518	10,000	9,422
	RNAV (A)	0	NA	NA
	RNAV (B)	8,500	$ 2,295	$ 2,015
	RNAV (C)	250	12,998	6,677
	RNAV (D)	250	12,998	6,677
SELF-CONTAINED	INS	468	$110,000	$62,160
	OTHER S.C.	1,264	25,000	16,430
LORAN-C	LORAN-C (A)	100	$ 6,708	$ 2,998
	LORAN-C (B)	100	7,937	3,547
	LORAN-C (C)	100	11,405	5,097
	LORAN-C (D)	1,000	17,617	11,173
OMEGA	OMEGA (A)	100	$ 6,708	$ 2,998
	OMEGA (B)	100	7,937	3,547
	OMEGA (C)	100	11,405	5,097
	OMEGA (D)	1,000	17,617	11,173
DIFF. OMEGA	DIFF. OMEGA (A)	100,000 Diff.*, 100 Omega	$ 7,458	$ 3,748
	DIFF. OMEGA (B)	100,000 Diff., 100 Omega	8,703	4,313
	DIFF. OMEGA (C)	100,000 Diff., 100 Omega	12,219	5,911
	DIFF. OMEGA (D)	100,000 Diff., 1,000 Omega	18,617	12,173
GPS	GPS (A)	50	$ 14,331	$ 5,765
	GPS (B)	50	16,704	6,719
	GPS (C)	50	25,462	10,242
	GPS (D)	50	57,680	23,201

* ASSUMED TO REFLECT THE PRODUCTION BASE ASSOCIATED WITH ADF's, ESTIMATED TO BE GREATER THAN 100,000 UNITS, THEREBY, PRODUCING NO SUBSEQUENT PRODUCTION BASE RELATED COST REDUCTIONS.

\+ 1977 DOLLARS

Table 4.5

RAANS Estimated Enroute Navigation Price Per Package by System Type and Avionics Category

NAVIGATION SYSTEM TYPE	RAANS AVIONICS CATEGORY NUMBER	RAANS 1977 PRICE PER PACKAGE	PKG. PRICE,* 20,000 AND SUBSEQUENT COMPONENTS
VOR	1	$ 1,495	$ 1,495
	2	2,990	2,990
	3	6,903	6,903
	4	10,586	10,583
	5	9,198	8,918
	6	23,584	17,260
	7	27,338	26,682
	8	27,838	25,682
	9	27,338	26,682
	10	40,336	33,359
VOR PLUS SELF-CONTAINED	1	$ 26,695	$ 17,925
	2	27,990	19,420
	3	31,903	23,333
	4	35,586	27,013
	5	34,198	25,348
	6	48,584	33,690
	7	77,838	59,542
	8	247,833	151,002
	9	357,833	213,162
	10	90,836	66,219
VOR PLUS OMEGA SUB-STITUTED FOR SELF-CONTAINED	1	$ 8,203	$ 4,493
	2	16,406	8,986
	3	21,548	13,448
	4	29,928	19,227
	5	25,072	16,012
	6	46,394	27,454
	7	63,072	49,028
	8	63,072	49,028
	9	63,072	49,028
	10	76,070	55,705
LORAN-C	1	$ 6,708	$ 2,998
	2	13,416	5,996
	3	14,645	6,545
	4	19,342	8,644
	5	15,874	7,094
LORAN-C (Cont'd)	6	$ 22,810	$10,194
	7	35,234	22,346
	8	35,234	22,346
	9	35,234	22,346
	10	35,234	22,346
OMEGA	1	$ 6,708	$ 2,998
	2	13,416	5,996
	3	14,645	6,545
	4	19,342	8,644
	5	15,874	7,094
	6	22,810	10,194
	7	35,234	22,346
	8	35,234	22,346
	9	35,234	22,346
	10	35,234	22,346
DIFF. OMEGA	1	$ 7,458	$ 3,748
	2	14,916	7,495
	3	16,161	8,061
	4	20,922	10,224
	5	17,406	8,626
	6	24,438	11,822
	7	37,234	24,346
	8	37,234	24,346
	9	37,234	24,346
	10	37,234	24,346
GPS	1	$ 14,331	$ 5,765
	2	28,662	11,530
	3	31,035	12,484
	4	42,166	16,961
	5	33,408	13,438
	6	50,924	20,484
	7	115,360	46,402
	8	115,360	46,402
	9	115,360	46,402
	10	115,360	46,402

* 1977 DOLLARS

V. IMPLEMENTATION SCENARIOS

As used in this study, an implementation scenario provided the means to define, for a given computer run, the following:

(1) The type of navigation system(s) that will be certified for civil aviation operations through the year 2005 (end of RAANS planning horizon).

(2) Which of the RAANS operating regions (CONUS, Alaska, CONUS Off-shore, Alaska Off-shore and Oceanic) will be serviced by each of the systems defined in (1).

(3) The implementation period dates, for each system-region combination identified in (2) (i.e., the beginning and ending dates when either improvements are being implemented on current systems or alternative systems are being developed and brought to an operational state).

(4) The transition period dates for each operating region (i.e., the beginning and ending dates of the period when both the current navigation system and its replacement alternative system are operational).

(5) The operating dates associated with each system identified in (1).

(6) The annual distribution of implementation cost expenditures over the implementation period of (3).

(7) Modifications to the nominal run conditions (such as changing the annual inflation rate). This implementation scenario feature was used primarily in the sensitivity analysis.

Definition of the implementation scenarios used to produce this study's FAA and NAS user cost results are defined in the following subsections.

5.1 BASELINE SCENARIOS

These were "no change" scenarios, wherein versions of the current navigation systems remained operational through the entire RAANS planning period and no alternatives were introduced. The

nominal baseline case was developed primarily to provide a consistent means of assessing the relative impact on FAA and user costs that resulted from the implementation of alternative systems. Each baseline scenario encompassed the continuing operation of the two current systems: (1) VOR for the CONUS and Alaska regions, and (2) "self-contained" for CONUS off-shore, Alaska off-shore and/or oceanic operations. There were, however, different versions of each of these two systems.

The VOR system could evolve into either the "second generation" VOR or the "upgraded" VOR. In either case, the implementation costs required for the specified modification had to be properly allocated. The annual recurring costs, normally modeled as a constant, also had to be adjusted to account for the larger than normal values that occur before the total benefits of the yet to be completed modifications (upgraded or second generation VOR) are realized.

The self-contained system category, as originally conceived for use in this study, included only truly self-contained navigation systems for over water operations such as INS or Doppler radar. During the course of this analysis it became apparent that the introduction of Omega to either supplement or replace the self-contained systems had already begun. The RAANS methodology, however, was not initially designed with the capability to consider transitions currently in progress. Thus, two scenario options were available: (1) to assume that the transition to Omega was completed, or (2) that the transition would start some time after the RAANS base year of 1978.

A nominal baseline scenario was established (Run 100) which had the prevailing VOR system evolving to the second generation VOR system. In this scenario, Omega was deemed to have completely replaced the self-contained systems prior to the start of the RAANS planning period, i.e., 1978. Two other baseline scenarios were designed to facilitate an evaluation of the effects of stipulating second generation VOR rather than the upgraded version

and the continuous use of Omega rather than transitioning from self-contained to Omega. Run 101 had VOR evolving to an "upgraded VOR" system but retained the nominal baseline condition of a continuous Omega system in place of self-contained. Run 102 retained the nominal baseline VOR to second generation scenario but transitioned from the self-contained to Omega.

5.2 ALTERNATIVE SYSTEM SCENARIOS

Four basic scenarios were developed in the RAANS study which represented the most likely applications of the three navigation system alternatives:

(1) Transition from VOR in Alaska and Alaska off-shore to differential Omega. Retain VOR in the CONUS and continue to use Omega in the CONUS off-shore and oceanic regions.

(2) Transition to Loran-C in all operating regions but oceanic. Continue to use Omega for oceanic operations.

(3) Transition to GPS in all regions.

(4) Transition to GPS in all regions but retain the second generation VOR system in CONUS and Alaska to support the operations of the "low cost avionics" user groups (RAANS avionics categories 1 and 2) in those regions.

From five to seven different implementation schedules were used with each of the four basic scenarios described above. Generally, for each of the alternative systems, the implementation costs were spread uniformly over the designated implementation period. The annual recurring costs were increased linearly from zero in the year preceding the start of the implementation period to its full steady state value in the final implementation year.

The characteristics of the implementation scenarios used in the RAANS study are summarized in Table 5.1. Nominal (most likely) scenario schedules are indicated for each of the four basic scenarios plus the baseline. Run numbers are listed to facilitate referencing the results to specific scenarios. The

Table 5.1

Summary of RAANS Navigation Systems' Implementation Scenarios

BASELINE "NO CHANGE" SCENARIOS

NOMINAL SCENARIO	RUN NO.	AFFECTED USER GROUPS		NAVIGATION SYSTEM	IMPLEMENTATION-TRANSITION SCHEDULE																											
		AVIONICS CATEGORIES	OPERATING REGIONS		78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05
✱	100	ALL	CONUS, ALASKA	2nd GEN VOR																												
		ALL	OCEANIC, OFFSHORE	S.C. (OMEGA)																												
	101	ALL	CONUS, ALASKA	UPGRADED VOR																												
		ALL	OCEANIC, OFFSHORE	S.C. (OMEGA)																												
	102	ALL	CONUS, ALASKA	2nd GEN VOR																												
		ALL	OCEANIC, OFFSHORE	S.C. (INS, OTHER)																												
				S.C. (OMEGA)																												

——— NAVIGATION SYSTEM OPERATIONAL FOR CIVIL AVIATION

- - - - NAVIGATION SYSTEM IMPLEMENTATION PHASE (PRIOR TO ACHIEVING CIVIL AVIATION OPERATIONAL STATUS)

—-— NAVIGATION SYSTEM OPERATIONAL FOR CIVIL AVIATION, INCREMENTAL IMPLEMENTATION IMPROVEMENTS (AND COSTS) OCCURRING DURING THIS PHASE

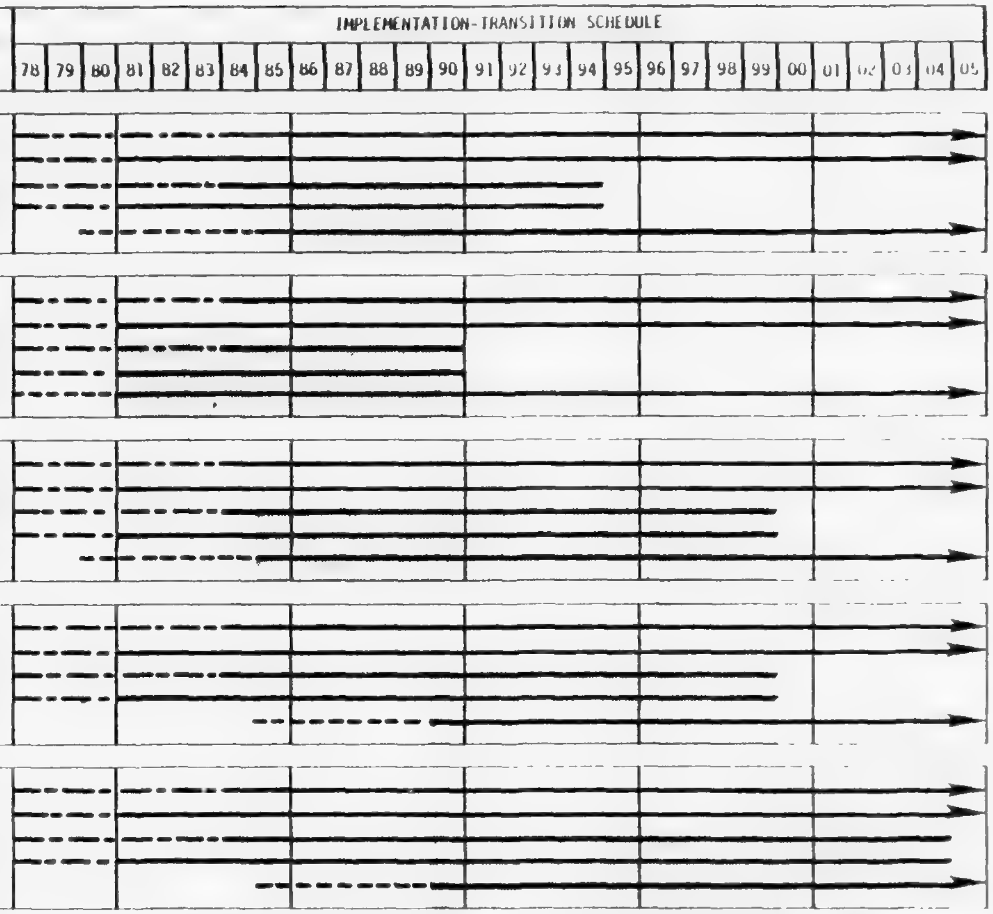
TRANSITION PERIOD, DURING WHICH BOTH CURRENT AND ALTERNATIVE NAVIGATION SYSTEMS ARE OPERATIONAL IN THE DESIGNATED REGIONS

Table 5.1 (Continued)

Summary of RAANS Navigation Systems' Implementation Scenarios

TRANSITION TO DIFFERENTIAL OMEGA IN ALASKA AND ALASKA OFFSHORE

NOMINAL SCENARIO	RUN NO.	AFFECTED USER GROUPS: AVIONICS CATEGORIES	AFFECTED USER GROUPS: OPERATING REGIONS	NAVIGATION SYSTEM
✱	202	ALL	CONUS, OCEANIC	2nd GEN VOR
			CONUS OFFSHORE	S.C. (OMEGA)
			ALASKA	2nd GEN VOR
		ALL	ALASKA	S.C. (OMEGA)
			OFFSHORE	DIFF OMEGA
	200	ALL	CONUS, OCEANIC	2nd GEN VOR
			CONUS OFFSHORE	S.C. (OMEGA)
			ALASKA	2nd GEN VOR
		ALL	ALASKA	S.C. (OMEGA)
			OFFSHORE	DIFF OMEGA
	205	ALL	CONUS, OCEANIC	2nd GEN VOR
			CONUS OFFSHORE	S.C. (OMEGA)
			ALASKA	2nd GEN VOR
		ALL	ALASKA	S.C. (OMEGA)
			OFFSHORE	DIFF OMEGA
	204	ALL	CONUS, OCEANIC	2nd GEN VOR
			CONUS OFFSHORE	S.C. (OMEGA)
			ALASKA	2nd GEN VOR
		ALL	ALASKA	S.C. (OMEGA)
			OFFSHORE	DIFF OMEGA
	206	ALL	CONUS OCEANIC	2nd GEN VOR
			CONUS OFFSHORE	S.C. (OMEGA)
			ALASKA	2nd GEN VOR
			ALASKA	S.C. (OMEGA)
			OFFSHORE	DIFF OMEGA



——— NAVIGATION SYSTEM OPERATIONAL FOR CIVIL AVIATION

– – – – NAVIGATION SYSTEM IMPLEMENTATION PHASE (PRIOR TO ACHIEVING CIVIL AVIATION OPERATIONAL STATUS)

—– – — NAVIGATION SYSTEM OPERATIONAL FOR CIVIL AVIATION, INCREMENTAL IMPLEMENTATION IMPROVEMENTS (AND COSTS) OCCURRING DURING THIS PHASE

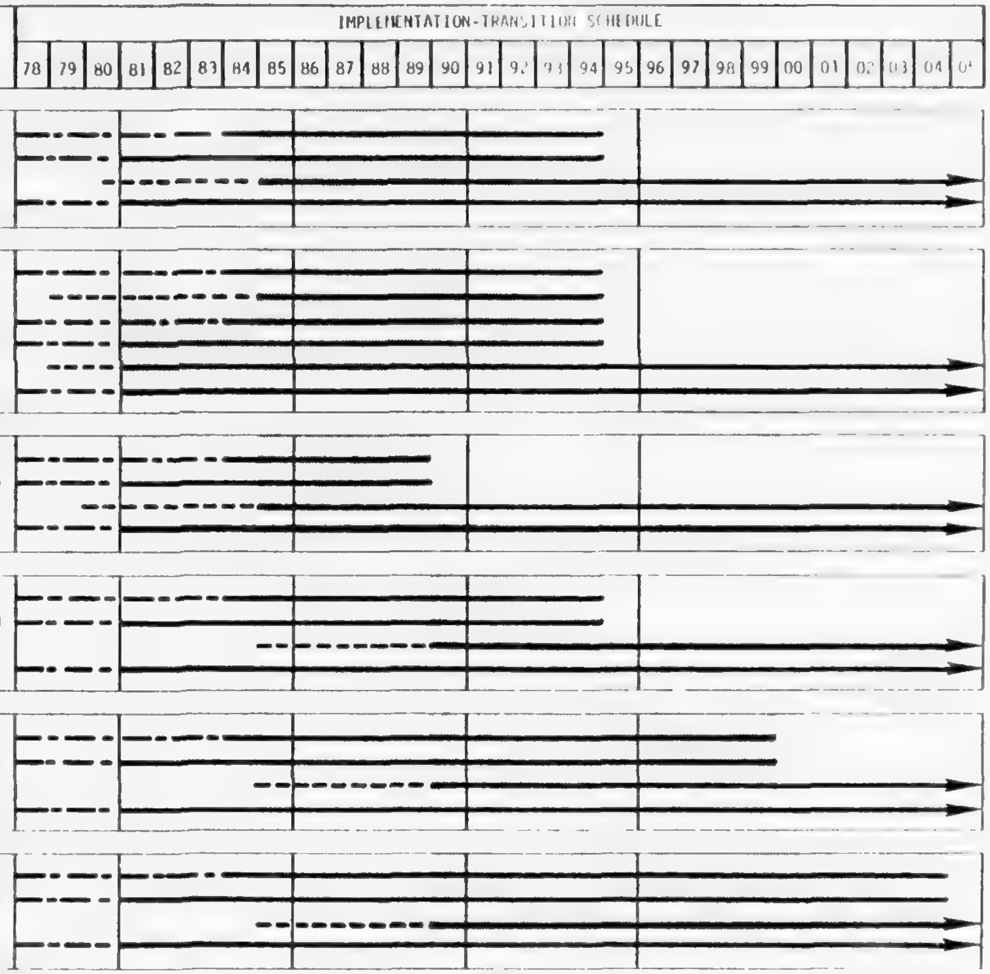
TRANSITION PERIOD, DURING WHICH BOTH CURRENT AND ALTERNATIVE NAVIGATION SYSTEMS ARE OPERATIONAL IN THE DESIGNATED REGIONS

Table 5.1 (Continued)

Summary of RAANS Navigation Systems' Implementation Scenarios

TRANSITION TO LORAN-C ALL REGIONS BUT OCEANIC

NOMINAL SCENARIO	RUN NO.	AFFECTED USER GROUPS: AVIONICS CATEGORIES	AFFECTED USER GROUPS: OPERATING REGIONS	NAVIGATION SYSTEM
✱	302	ALL	CONUS, ALASKA OFFSHORE	2nd GEN VOR S.C. (OMEGA) LORAN-C
		ALL	OCEANIC	S.C. (OMEGA)
	300	ALL	CONUS	2nd GEN VOR LORAN-C
		ALL	ALASKA OFFSHORE	2nd GEN VOR S.C. (OMEGA) LORAN-C
		ALL	OCEANIC	S.C. (OMEGA)
	301	ALL	CONUS ALASKA OFFSHORE	2nd GEN VOR S.C. (OMEGA) LORAN-C
		ALL	OCEANIC	S.C. (OMEGA)
	303	ALL	CONUS, ALASKA OFFSHORE	2nd GEN VOR S.C. (OMEGA) LORAN-C
		ALL	OCEANIC	S.C. (OMEGA)
	304	ALL	CONUS ALASKA OFFSHORE	2nd GEN VOR S.C. (OMEGA) LORAN-C
		ALL	OCEANIC	S.C. (OMEGA)
	306	ALL	CONUS ALASKA OFFSHORE	2nd GEN VOR S.C. (OMEGA) LORAN-C
		ALL		S.C. (OMEGA)



NAVIGATION SYSTEM OPERATIONAL FOR CIVIL AVIATION

NAVIGATION SYSTEM IMPLEMENTATION PHASE (PRIOR TO ACHIEVING CIVIL AVIATION OPERATIONAL STATUS)

NAVIGATION SYSTEM OPERATIONAL FOR CIVIL AVIATION, INCREMENTAL IMPLEMENTATION IMPROVEMENTS (AND COSTS) OCCURRING DURING THIS PHASE

TRANSITION PERIOD, DURING WHICH BOTH CURRENT AND ALTERNATIVE NAVIGATION SYSTEMS ARE OPERATIONAL IN THE DESIGNATED REGIONS

Table 5.1 (Continued)

Summary of RAANS Navigation Systems' Implementation Scenarios

TRANSITION TO GPS IN ALL REGIONS

NOMINAL SCENARIO	RUN NO.	AFFECTED USER GROUPS		NAVIGATION SYSTEM	IMPLEMENTATION-TRANSITION SCHEDULE (78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 00 01 02 03 04 05)
		AVIONICS CATEGORIES	OPERATING REGIONS		
✸	403	ALL	ALL	2nd GEN VOR S.C. (OMEGA) GPS	
	409	ALL	ALL	2nd GEN VOR S.C. (OMEGA) GPS	
	400	ALL	ALL	2nd GEN VOR S.C. (OMEGA) GPS	
	401	ALL	ALL	2nd GEN VOR S.C. (OMEGA) GPS	
	410	ALL	ALL	2nd GEN VOR S.C. (OMEGA) GPS	
	402	ALL	ALL	2nd GEN VOR S.C. (OMEGA) GPS	
	404	ALL	ALL	2nd GEN VOR S.C. (OMEGA) GPS	

NAVIGATION SYSTEM OPERATIONAL FOR CIVIL AVIATION

NAVIGATION SYSTEM IMPLEMENTATION PHASE (PRIOR TO ACHIEVING CIVIL AVIATION OPERATIONAL STATUS)

NAVIGATION SYSTEM OPERATIONAL FOR CIVIL AVIATION, INCREMENTAL IMPLEMENTATION IMPROVEMENTS (AND COSTS) OCCURRING DURING THIS PHASE

TRANSITION PERIOD, DURING WHICH BOTH CURRENT AND ALTERNATIVE NAVIGATION SYSTEMS ARE OPERATIONAL IN THE DESIGNATED REGIONS

Table 5.1 (Concluded)

Summary of RAANS Navigation Systems' Implementation Scenarios

TRANSITION TO GPS IN ALL REGIONS EXCEPT AVIONICS CATEGORIES 1 & 2 IN CONUS AND ALASKA

NOMINAL SCENARIO	SCEN. NO.	AFFECTED USER GROUPS: AVIONICS CATEGORIES	AFFECTED USER GROUPS: OPERATING REGIONS	NAVIGATION SYSTEM
✱	407	1&2	CONUS, ALASKA	2nd GEN VOR
		3-10	CONUS, ALASKA	2nd GEN VOR
		ALL	OCEANIC,	S.C. (OMEGA)
			OFFSHORE	GPS
	411	1&2	CONUS, ALASKA	2nd GEN VOR
		3-10	CONUS, ALASKA	2nd GEN VOR
		ALL	OCEANIC,	S.C. (OMEGA)
			OFFSHORE	GPS
	41[illegible]	1&2	CONUS, ALASKA	2nd GEN VOR
		3-10	CONUS, ALASKA	2nd GEN VOR
		ALL	OCEANIC,	S.C. (OMEGA)
			OFFSHORE	GPS
	[illegible]	1&2	CONUS, ALASKA	2nd GEN VOR
		3-10	CONUS, ALASKA	2nd GEN VOR
		ALL	OCEANIC,	S.C. (OMEGA)
			OFFSHORE	GPS
	412	1&2	CONUS, ALASKA	2nd GEN VOR
		3-10	CONUS, ALASKA	2nd GEN VOR
			OCEANIC,	S.C. (OMEGA)
			OFFSHORE	GPS
	406	1&2	CONUS, ALASKA	2nd GEN VOR
		3-10	CONUS, ALASKA	2nd GEN VOR
		ALL	OCEANIC,	S.C. (OMEGA)
			OFFSHORE	GPS
	40[illegible]	1&2	CONUS, ALASKA	2nd GEN VOR
		3-10	CONUS, ALASKA	2nd GEN VOR
		ALL	OCEANIC,	S.C. (OMEGA)
			OFFSHORE	GPS

IMPLEMENTATION TRANSITION SCHEDULE: 78 79 80 81 82 83 84 85 86 87 ...

——— NAVIGATION SYSTEM OPERATIONAL FOR CIVIL AVIATION

– – – NAVIGATION SYSTEM IMPLEMENTATION PHASE (PRIOR TO ACHIEVING CIVIL AVIATION OPERATIONAL STATUS)

—·— NAVIGATION SYSTEM OPERATIONAL FOR CIVIL AVIATION, INCREMENTAL IMPLEMENTATION IMPROVEMENTS [illegible]

TRANSITION PERIOD, DURING WHICH [illegible] NAVIGATION SYSTEMS ARE [illegible]

implementation and operating schedules for each of the navigation systems utilized in a given scenario between the years 1978 and 2005 is displayed by operating regions. Finally, the transition periods on a region specific basis are indicated.

VI. RESULTS

The preceding sections of this report have identified the means and supporting data that enable the quantification of FAA and NAS user costs resulting from specified navigation system scenarios. This section presents the results of applying this procedure to differential Omega, Loran-C, GPS and GPS with low cost VOR navigation system alternatives. To provide a common basis of comparison, the costs resulting from a "no change" baseline case are also presented. Finally, the cost variations resulting from modifications of selected study guidelines, ground rules and/or input cost estimates are illustrated.

6.1 BASELINE CASE

As described in Section 5.1, three baseline or "no change" scenarios were developed. The nominal baseline case (Run 100) had the current VOR system evolving into a "second generation" system for CONUS and Alaska users. For those users who also operated in either oceanic and/or off-shore regions, Omega supplemented VOR to provide the required civil air navigation over water capabilities.

To ascertain the impact of these nominal baseline case assumptions, two other baseline cases were developed and analyzed. Run 101 substituted an upgraded VOR for the second generation system while retaining Omega for oceanic and off-shore operations. The third baseline case, Run 102, retained the second generation VOR but transitioned from a self-contained system, i.e., INS, Doppler radar (with appropriate updates), to sole use of Omega for the oceanic and off-shore regions.

The results of this comparison are illustrated in Figure 6.1, which displays the cumulative present value cost buildup for the NAS users, the FAA and the combined user plus FAA costs.

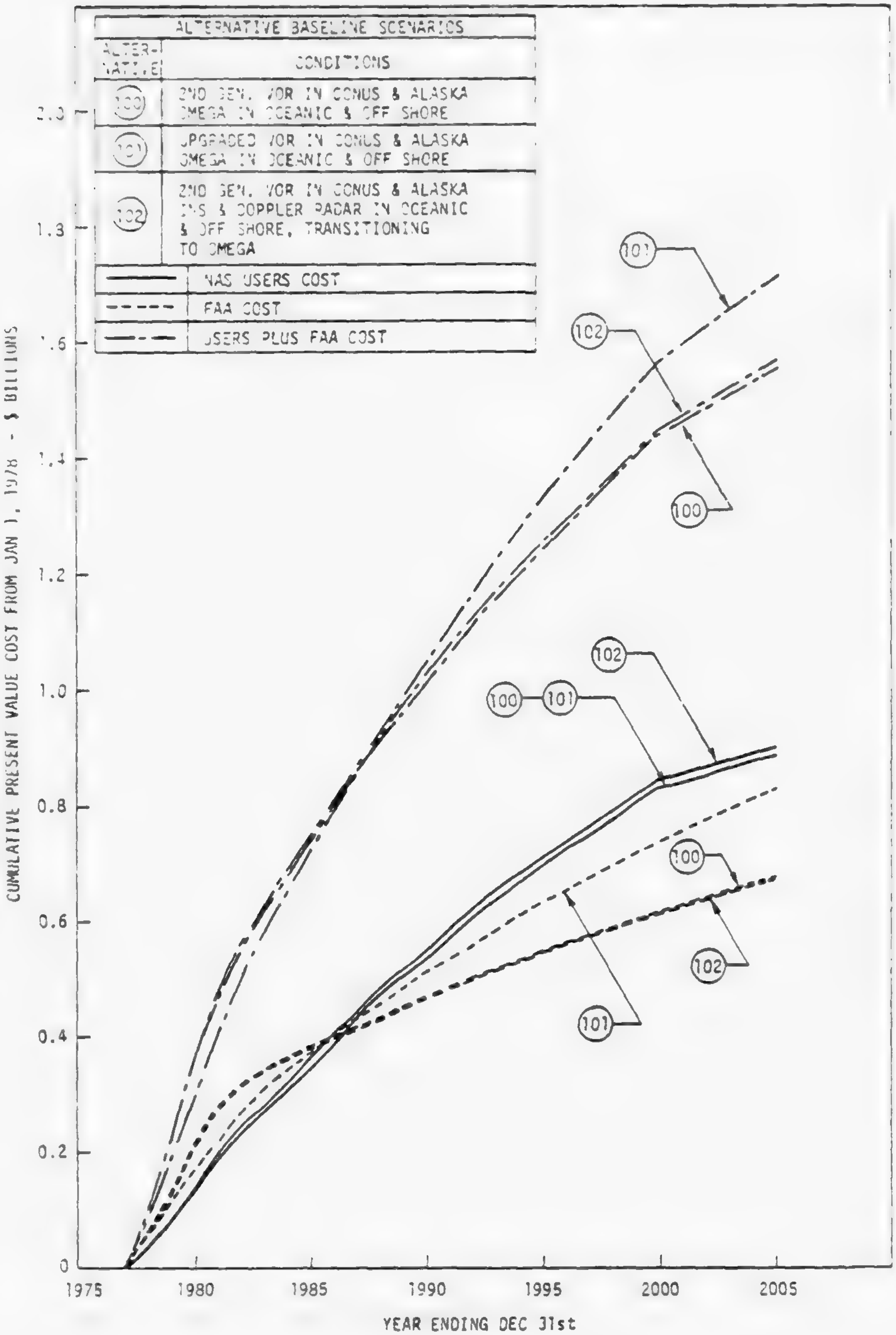


Figure 6.1 Alternative Baseline Scenarios
(7% Inflation; 10% Present Value Discount)

The following observations may be drawn from these curves:

(1) FAA (and total) costs are significantly lower for the scenarios using the second generation VOR than the scenario (101) using an upgraded VOR. This is due to the lower maintenance costs of the second generation system. The cross-over points for the FAA cost curves indicate that the front end implementation costs associated with second generation VOR (Volume II, Appendix B) are amortized by approximately 1987.

(2) User costs (as expected) are higher when using INS and Doppler Radar for oceanic and/or off-shore naivgation than when using Omega.

(3) The users, as expected, perceived no difference between the second generation and upgraded VOR systems; hence, the user costs of Runs 100 and 101 were identical.

The break in the user cost curves at the year 2000 reflects that the aircraft fleet projections, provided by the FAA, were not extrapolated after that year (i.e., no new aircraft were added and no aircraft retired). This study guideline, which is currently being modified, resulted in slightly conservative cumulative (through the year 2005) user cost estimates.

The 1978 through 2005 cumulative costs, both in terms of present value and after tax cash outlay, for each of the three baseline cases, is presented in the bar chart of Figure 6.2. The second generation VOR system (Runs 100 and 102) is more cost effective than upgraded VOR (Run 101). The cost differences induced by assuming Omega to be operational from the beginning of the RAANS planning period (Run 100) rather than transitioning from self-contained to Omega (Run 102) appeared to be negligible. For these reasons and because the initial RAANS methodology could not accommodate multiple transitions, e.g., from self-contained to Omega to GPS, Run 100 was selected as the nominal baseline case. All alternative scenarios, discussed in the next section, were initiated with the nominal baseline case systems and differed only when the alternative system's implementation period was initiated.

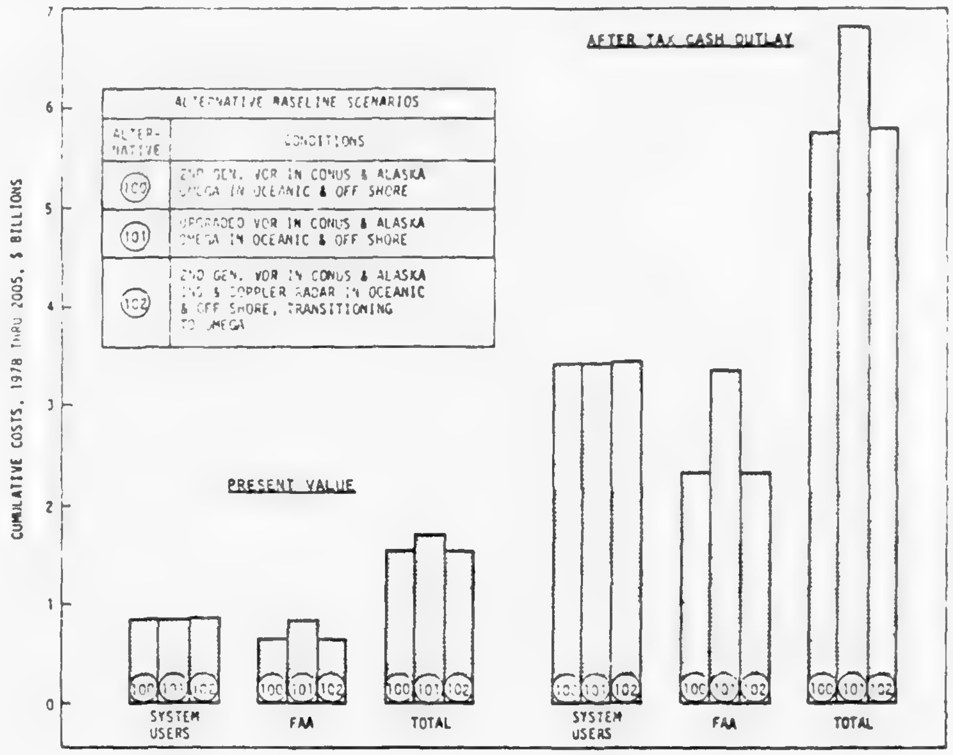


Figure 6.2 Comparison of Alternative Baseline Scenarios
(7% Inflation, 10% Present Value Discount Rate)

6.2 ALTERNATIVE NAVIGATION SYSTEMS

Comparison of the user and FAA costs resulting from each of the alternatives (including the baseline) are presented in the following subsections in terms of cumulative (1978-2005) totals; post-transition (steady state) annual recurring costs; implementation/transition schedule sensitivities; and individual user group impacts.

6.2.1 Alternative Navigation Systems Cost Impact Comparison

In addition to the baseline case, four basic navigation system alternatives were developed and subsequently evaluated in this study, specifically:

(1) Differential Omega in the Alaska and Alaska Off-shore regions; continued use of VOR/DME in CONUS and Omega for CONUS Off-shore and Oceanic;

(2) Loran-C in all regions with Omega providing Oceanic coverage;

(3) GPS in all regions; and

(4) GPS in all regions except second generation VOR retained in the CONUS and Alaska regions for use by the "low cost avionics" users.

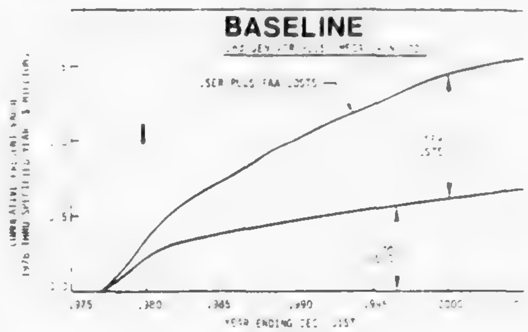
Nominal implementation scenarios (implementation and transition schedules) were developed for each of these four basic alternatives (Section 5.2). The resulting FAA and user present value cost build-ups for these nominal cases are illustrated in Figure 6.3. The baseline costs are also shown and are superimposed (shaded areas) on the alternative case costs for comparison purposes. The differential Omega case (Fig. 6.3-II), affecting only a small portion of the fleet (Alaska and Alaska off-shore), produces costs similar to the baseline case. Loran-C's nominal scenario costs (Fig. 6.3-III) start to deviate from the baseline at the start of the implementation period. The resulting total cost increase relative to the baseline scenario is divided about 35% FAA and 65% NAS users. The GPS scenario (Fig. 6.3-IV) produced the greatest cost increase of the alternatives examined. This increase was borne totally by the users with their baseline costs more than doubling. The FAA costs, reflecting the decommissioning of the VOR system declined. The GPS plus VOR for low cost avionics users in the CONUS and Alaska (Fig. 6.3-V) was developed to decrease the cost burden on the users essentially at the expense of the FAA. The total costs were less than the total GPS (Fig. 5.3-IV) with the FAA absorbing 12% of the increase relative to the baseline cost with the NAS users absorbing the balance.

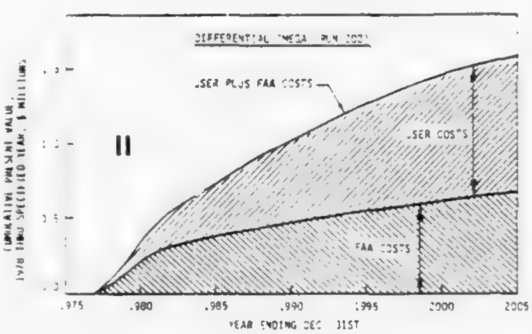
RUN NO.	NAVIGATION SYSTEM	IMPLEMENTATION PERIOD	TRANSITION PERIOD
[illegible]	BASELINE - 2ND GEN VOR IN CONUS & AKA, OMEGA IN OCEANIC & OFFSHORE	NA	NA
[illegible]	DIFF OMEGA IN AKA & AKA [illegible] OME IN CONUS, OMEGA IN [illegible]	1980 THRU 1984	1985 THRU 1994
[illegible]	LORAN-C IN ALL REGIONS EXCEPT OMEGA FOR OCEANIC COVERAGE	1980 THRU 1984	1985 THRU 1994
403	GPS IN ALL REGIONS	1985 THRU 1989	1990 THRU 1999
[illegible]	GPS VOR - GPS IN ALL REGIONS EXCEPT LOW COST VOR RETAINED IN CONUS & ALASKA	1985 THRU 1989	1990 THRU 1999

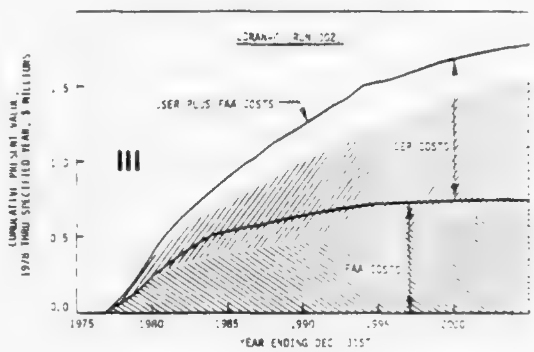
BASELINE (2nd GEN VOR/OMEGA) COMPARISON DATA

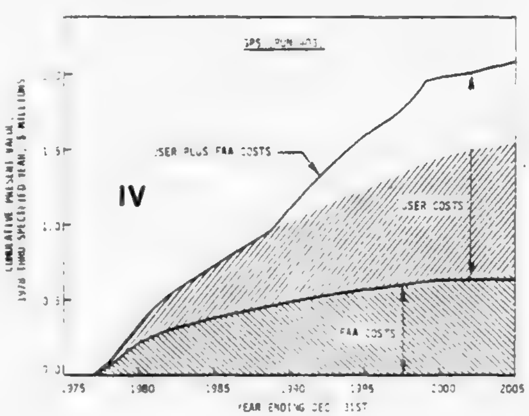
USER COSTS

FAA COSTS









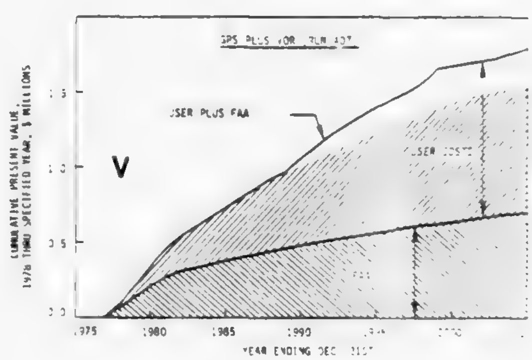


Figure 6.3 Navigation Systems Cost Buildup Comparisons (Annual Inflation Rate = 7%; Present Value Discount Rate = 10%; Nominal Implementation Scenario for Each System)

The cumulative 1978 to 2005 cost results for each implementation scenario analyzed in this study are summarized in the bar charts of Figure 6.4. Both present value and after tax cash outlay totals are presented. The shaded area on each bar reflects the range of costs associated with the different implementation/transition schedules examined.* All of the navigation system alternatives produce greater 1978-2005 cumulative user costs than the baseline case. The costs increase from the differential Omega alternative, which barely exceeded the baseline value, to the Loran-C, then GPS with VOR in CONUS and Alaska, and finally GPS, the alternative with the greatest user costs (with some scenarios producing more than double the baseline user costs). The positions of GPS and the baseline are essentially reversed with respect to the FAA 1978-2005 cumulative costs, with GPS producing the lowest cost (since it was assumed that all major GPS implementation and recurring costs will be absorbed by the military). The magnitude of the user costs relative to those incurred by the FAA results in a total (user plus FAA) navigation system cost pattern that is similar to that shown for the users only.

Table 6.1 lists the numerical cost values used to construct Figure 6.4.

6.2.2 Post-Transition Alternative System Cost Comparison

In addition to the cumulative costs 1978 through the year 2005 (which included one-time FAA implementation costs and possibly user "unscheduled" retrofit costs), the "steady state" post-transition costs were also of interest. To ensure a consistent set of comparative results, not biased by the fluctuations in aircraft fleet projections from year-to-year, a common implementation/transition period was used (implementation from 1980-1984, transition from 1985-1994) and applied to each of the four basic

*The shaded area for the baseline case reflects the range of costs primarily produced by second generation and upgraded VOR systems, respectively. See Figure 6.2.

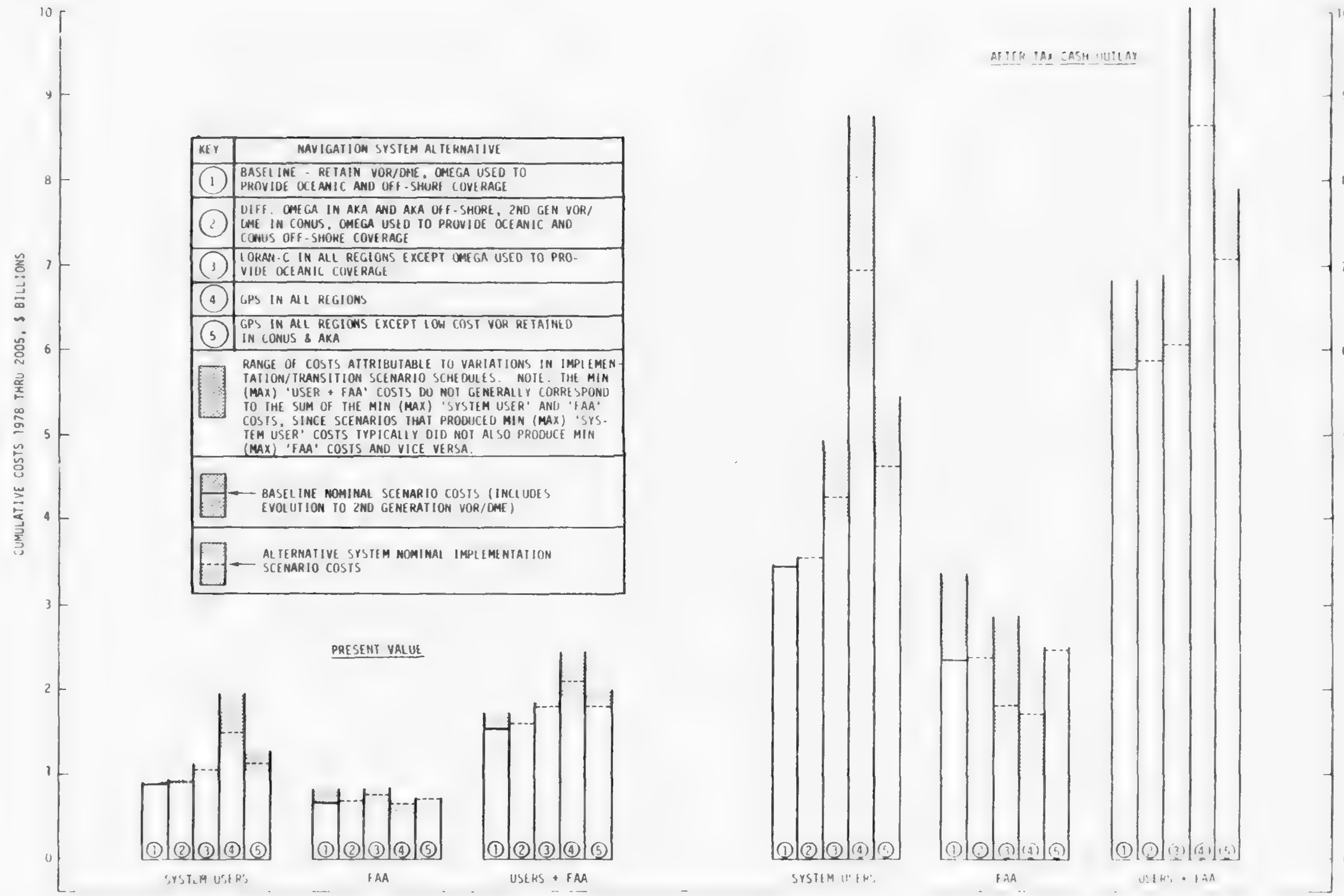


Figure 6.4 Air Navigation System Alternatives — Cost Comparison (Annual Inflation Rate = 7%, Present Value Discount Rate = 10%)

Table 6.1

Cost Summaries

RUN NO.	DESCRIPTION	CUMULATIVE COSTS THROUGH THE YEAR 2005 - $K					
		AFTER TAX CASH OUTLAY			PRESENT VALUE		
		USERS	FAA	TOTAL	USERS	FAA	TOTAL
	NO CHANGE SCENARIOS						
★[illegible]	NOMINAL BASELINE-FOR 2ND GEN OMEGA	[illegible]	2,336,324	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	UPGRADED [illegible] IN PLACE OF [illegible] OMEGA [illegible]	3,445,748	3,392,242	6,837,990	891,375	[illegible]	[illegible]
[illegible]	[illegible] 2ND GEN TRANS FROM [illegible] IN OCEANIC & [illegible]	3,474,010	[illegible],333,358	5,807,369	896,139	669,939	[illegible]
	TRANSITION TO DIFF. OMEGA [illegible] & [illegible] OFFSHORE						
[illegible]	IMPL [illegible] TRAN [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
★[illegible]	IMPL [illegible] TRAN [illegible]	3,543,646	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	IMPL [illegible] TRAN [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	IMPL [illegible] TRAN [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	IMPL [illegible] TRAN [illegible]	[illegible]	[illegible],402,644	[illegible]	[illegible]	[illegible]	[illegible],575,264
	TRANSITION TO [illegible]						
300	IMPL [illegible] - 1984 TRAN [illegible] - 1994 [illegible] IMPL [illegible] TRAN [illegible] - 1994 OTHER REG.	[illegible]	[illegible],794,361	6,254,495	[illegible]	[illegible]	[illegible]
301	IMPL [illegible] TRAN [illegible]	[illegible]	[illegible],495,945	[illegible]	[illegible]	[illegible]	[illegible]
★[illegible]	IMPL [illegible] TRAN [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	IMPL [illegible] TRAN [illegible]	[illegible]	[illegible]	6,272,725	[illegible]	[illegible]	[illegible]
[illegible]	IMPL 1985 - [illegible] TRAN [illegible]	[illegible]	[illegible],484,466	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	IMPL 1985 - [illegible] TRAN [illegible]	[illegible]	[illegible],294,363	[illegible]	[illegible]	[illegible]	[illegible]
306	IMPL 1985 - [illegible] TRAN [illegible]	[illegible]	[illegible],495,730	6,317,653	[illegible]	[illegible]	[illegible]
	TRANSITION TO [illegible]						
400	IMPL [illegible] TRAN [illegible]	[illegible]	[illegible]	[illegible]	[illegible],749,931	579,[illegible]	[illegible]
401	IMPL [illegible] TRAN [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	500,954	[illegible]
[illegible]	IMPL [illegible] TRAN [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	IMPL 1985 - [illegible] TRAN [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	567,986	[illegible]
★[illegible]	IMPL [illegible] TRAN [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	636,[illegible]	[illegible]
[illegible]	IMPL [illegible] TRAN [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	IMPL 1990 - 1994 TRAN [illegible]	[illegible]	[illegible]	[illegible]	[illegible],626	626,36[illegible]	[illegible]
	TRANSITION TO [illegible] [illegible]						
[illegible]	IMPL [illegible] - 1994 TRAN [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
405	IMPL [illegible] - 1984 TRAN [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	IMPL 1980 - [illegible] TRAN [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
406	IMPL 1985 - 1989 TRAN [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
★407	IMPL 1985 - 1989 TRAN [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
412	IMPL 1985 - [illegible] TRAN [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
409	IMPL 1990 - 1994 TRAN [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible],735,[illegible]

★ NOMINAL SCENARIOS

a. JANUARY 1ST OF SPECIFIED YEAR

b. DECEMBER 31ST OF SPECIFIED YEAR

navigation system alternatives. The average annual costs for the five year period following the completion of the transition period are presented in Figure 6.5. A comparison of Figures 6.4 and 6.5 reveals that the relative position of the steady state Loran-C costs improved for both the FAA and the users. The steady state after tax cash outlay user costs are lowest for the baseline, differential Omega and Loran-C alternatives with the GPS plus low cost VOR slightly higher and GPS (alone) almost doubling the costs of the other systems. For the FAA, Loran-C and GPS appear to be the most attractive from a post-transition cost point of view. Overall Loran-C appears to be the most economical post-transition option.

6.2.3 Implementation/Transition Schedule Cost Comparison

The variation of the FAA and NAS user cost buildup with changes in the implementation and transition period schedule is illustrated in Figure 6.6 using the nominal GPS scenario as an example. Charts I through III of Figure 6.6 have a common GPS implementation (not transition) period, namely five years, 1980 through 1984. Charts IV through VI also have a five year implementation period, initiated five years later, running from 1985 through 1989. Chart VII's implementation period is from 1990 through 1994. The transition period, i.e., when GPS and the baseline navigation systems (second generation VOR and Omega) are operated simultaneously, are varied in five year increments from five to fifteen in Charts I, II and III and again in Charts IV, V and VI, respectively.

The nominal GPS scenario results (Chart V) are superimposed on the other scenarios to provide an easily observed reference. The pronounced peak in the user costs of Charts I and IV reflects the "forced" avionics retrofitting that occurs when the transition period is substantially less than the estimated enroute navigation avionics lifetime (14 years for air carrier avionics, 11 years for

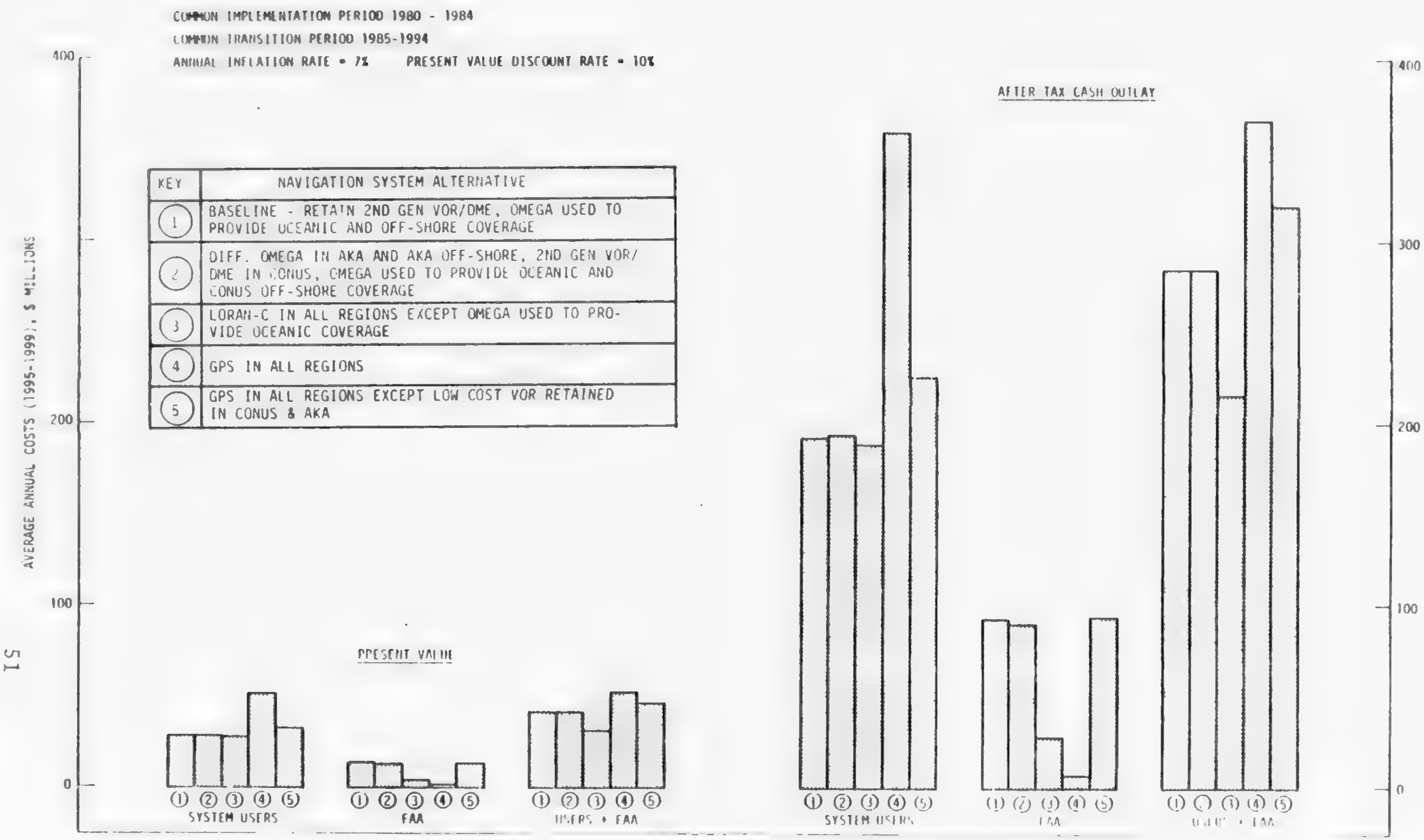


Figure 6.5 Example of Post Transition Average Annual Recurring Costs for Five Years Immediately Following Transition Period

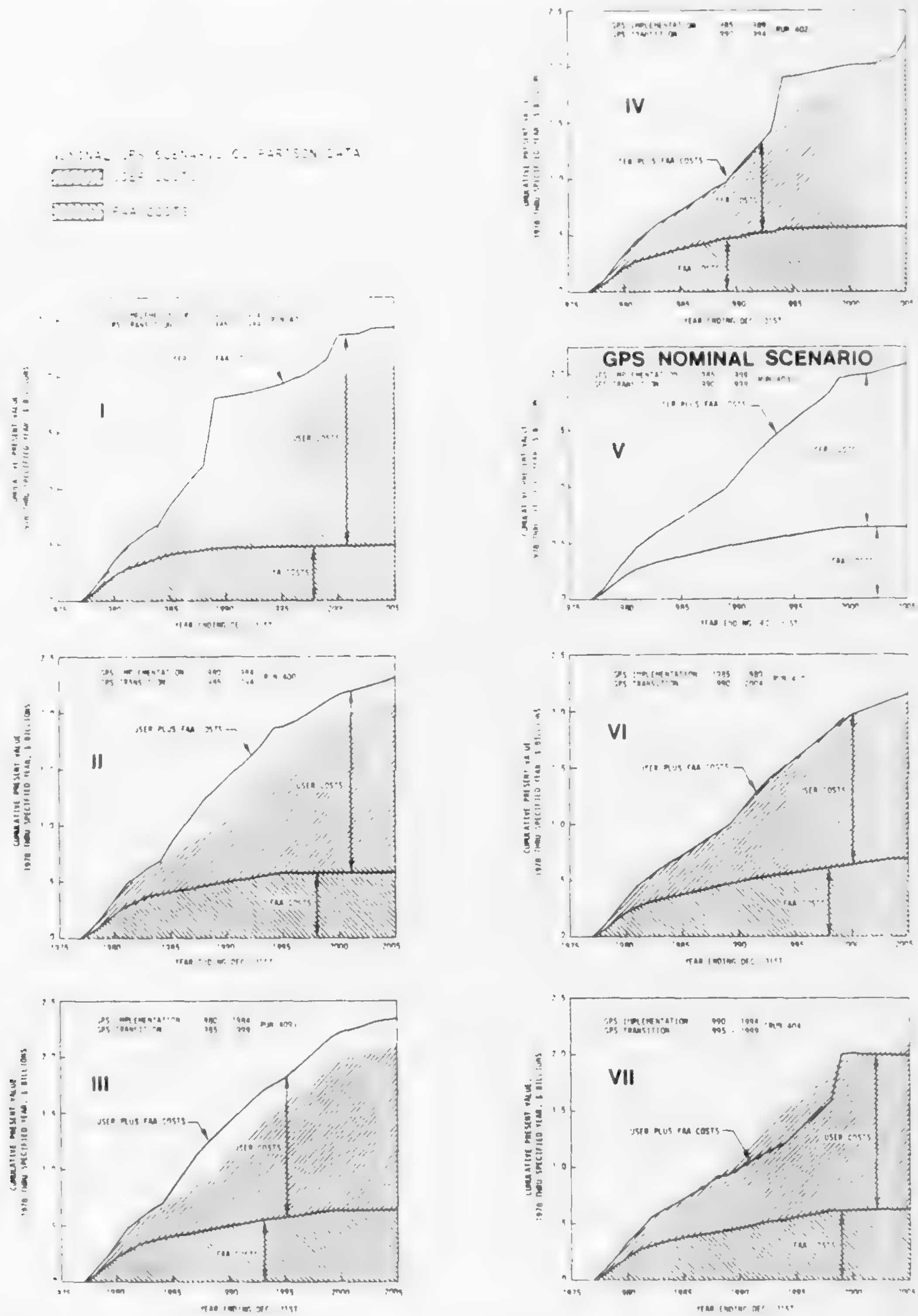


Figure 6.6 Impact of Implementation/Transition Schedules on Cost Buildups, Transition to GPS All Regions Example (Annual Inflation Rate = 7%, Present Value Discount Rate = 10%)

all others - see Volume II, Appendix A for the derivation of these values).

The sensitivities of cumulative (1978-2005) present value FAA and NAS user costs to transition schedule parameters (start date and duration) are illustrated by the curves of Figure 6.7 using the year ending Dec. 31st, 2005 values of Figure 6.6. As anticipated, the FAA costs increase with longer transition periods reflecting longer periods of multiple system operating expenses. NAS user costs tend to increase sharply as the duration of the transition period is decreased below the estimated general aviation enroute navigation avionics lifetime of 11 years (Volume II, Appendix A). The combination of these opposite trends (FAA vs. user) generally produces FAA plus user cost minimums somewhere between a 10 and 15 year transition duration. This observation also applies to transitions to the other major navigation system alternatives, such as Loran-C as shown in Figure 6.8.

As a general rule, the further into the future initiation of the transition period is moved, the less costly that scenario becomes to the users (as well as the user plus FAA totals). This can be attributed to the anticipated combination of avionics technology annual cost reduction factor (5.1%) and present value discount rate (10%) being greater than the estimated inflation rate (7%). The reverse is typically true for the FAA costs, due primarily to a longer (pre-transition) period of operating the generally more expensive VOR system before it is decommissioned.

6.2.4 Individual User Group Cost Impacts

The RAANS study approach divided the NAS users into 98 groups distinguished by type of operation, operating regions, avionics category and aircraft type. It was, therefore, possible to determine the cost impact of a given navigation system implementation on any of the 98 user groups. Figure 6.9 defines relevant cost impacts

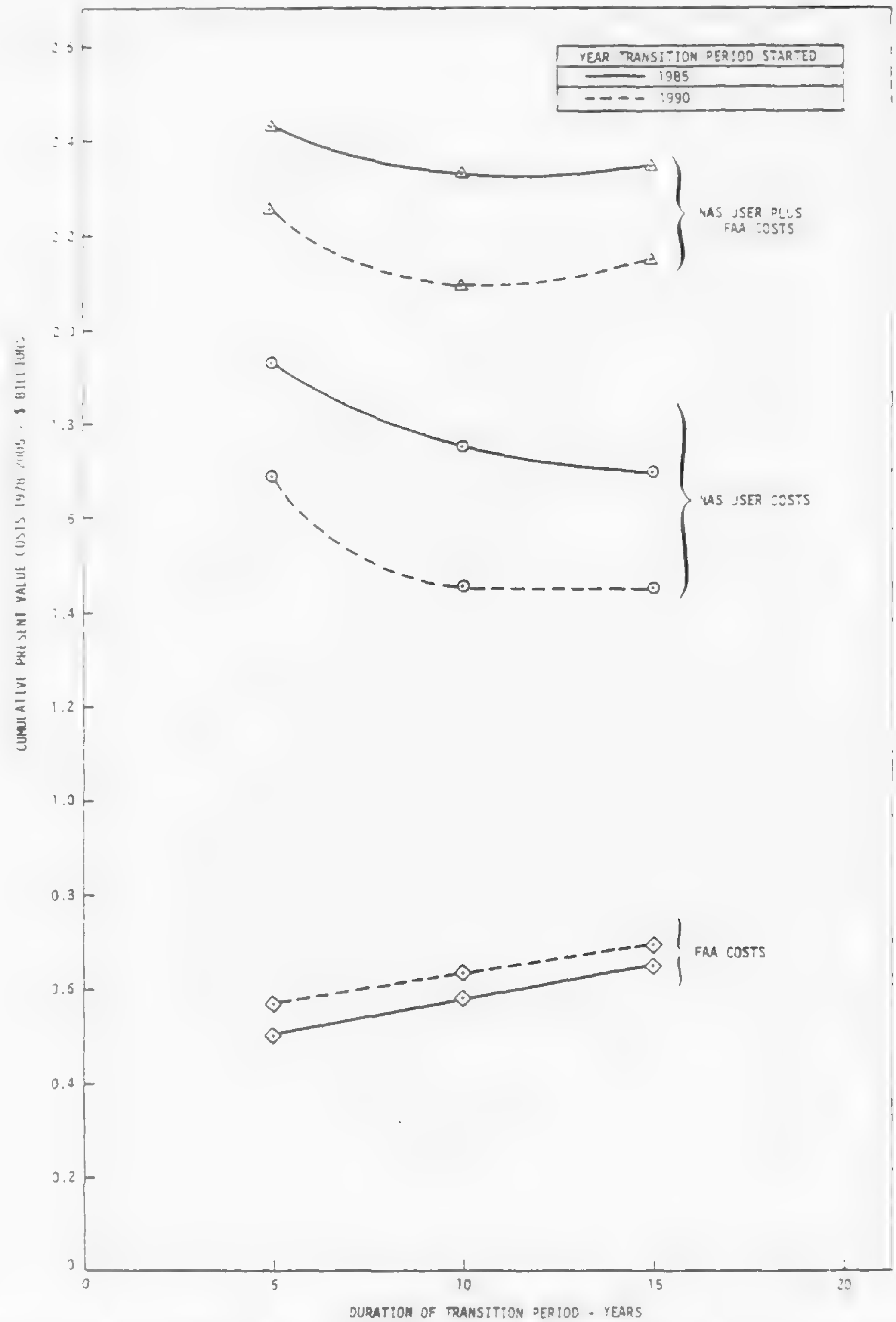


Figure 6.7 Example of NAS User and FAA Cumulative Present Value Cost (1978-2005) Sensitivities to Transition Period Schedule, Transition to GPS in All Operating Regions (Annual Inflation Rate = 7%, Present Value Discount Rate = 10%)

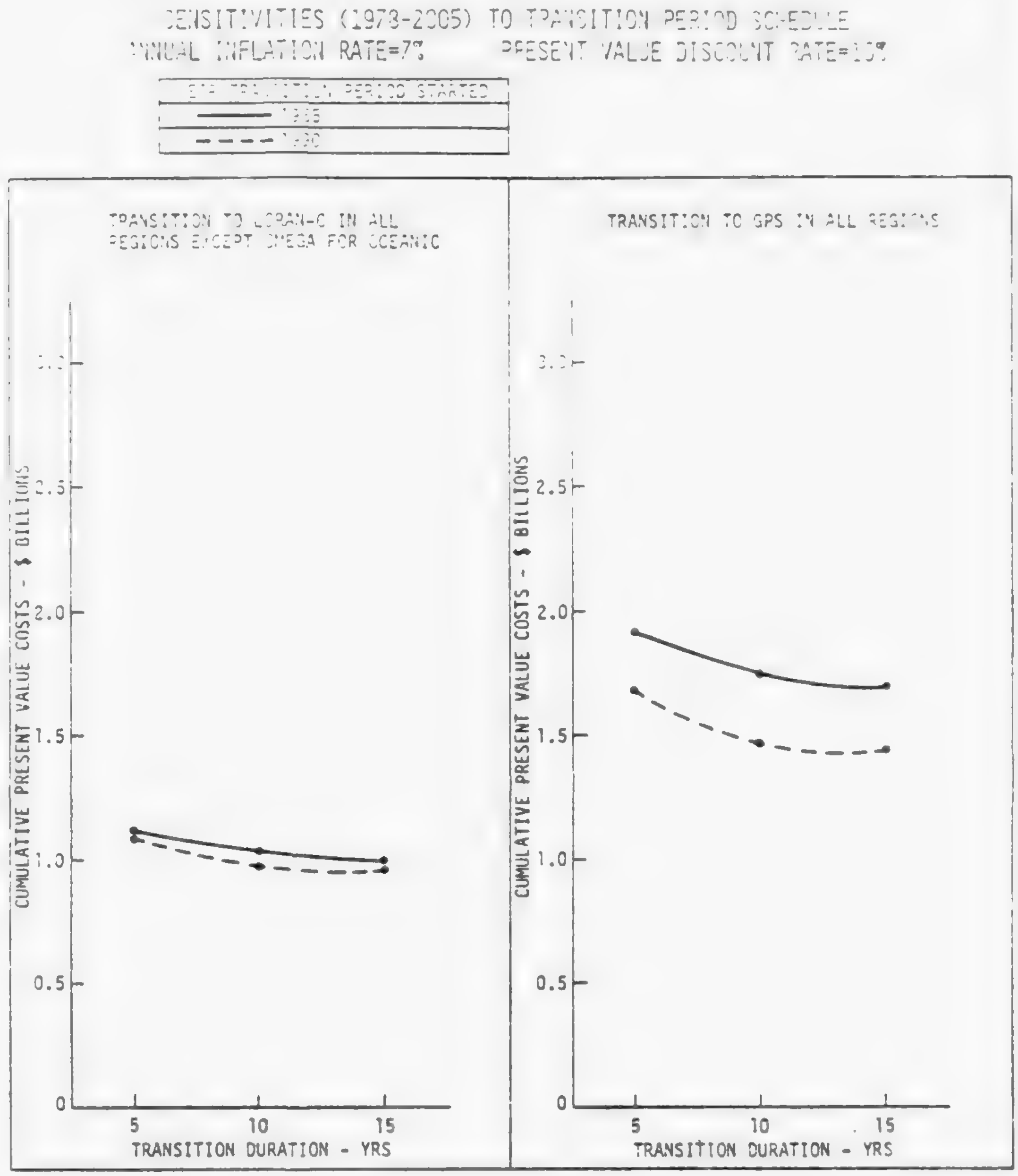
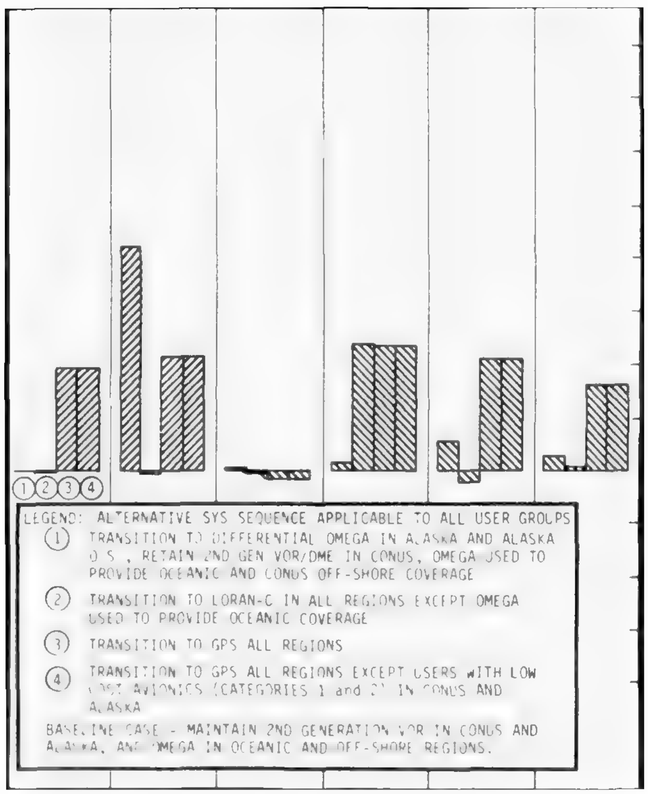
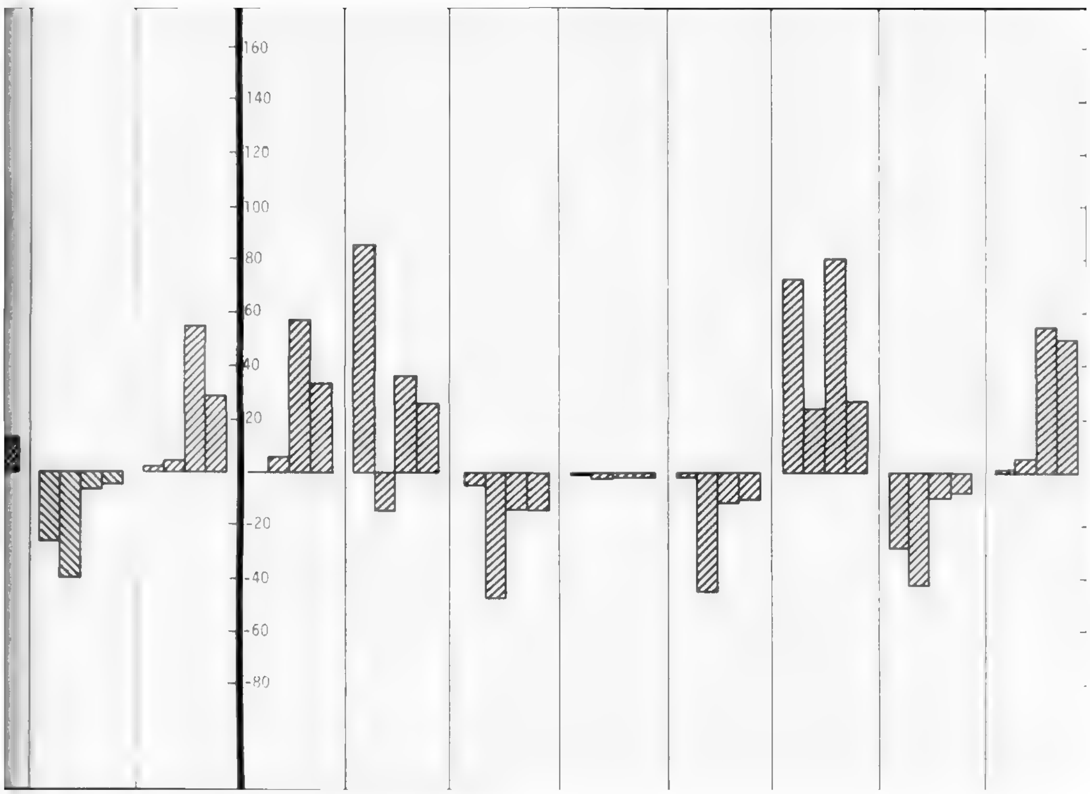
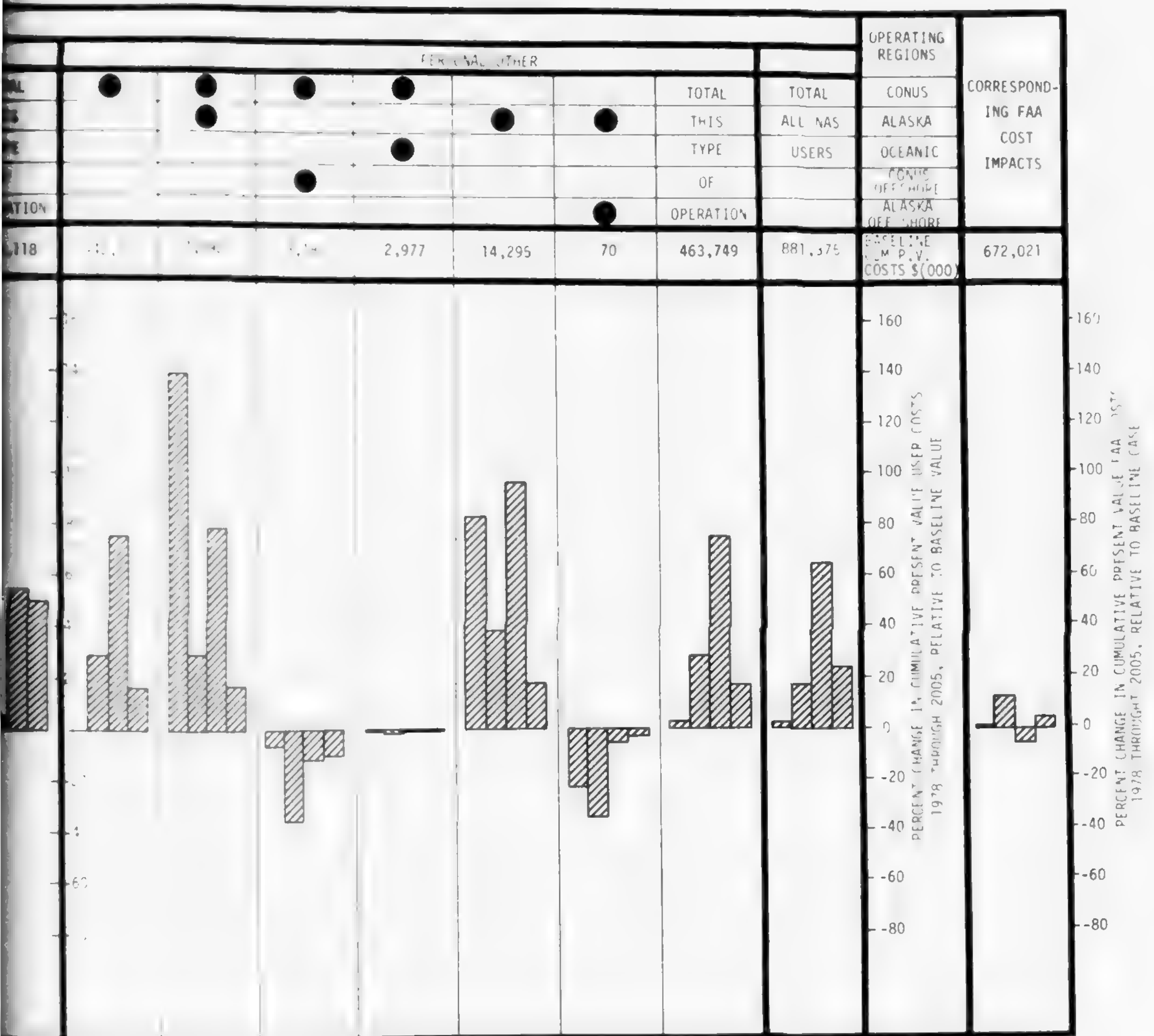


Figure 6.8 User Plus FAA Cumulative Present Value Cost Sensitivities (1978-2005) to Transition Period Schedule



1 2 3 4
LEGEND: ALTERNATIVE SYS SEQUENCE APPLICABLE TO ALL USER GROUPS
1 TRANSITION TO DIFFERENTIAL OMEGA IN ALASKA AND ALASKA O.S., RETAIN 2ND GEN VOR/DME IN CONUS, OMEGA USED TO PROVIDE OCEANIC AND CONUS OFF-SHORE COVERAGE
2 TRANSITION TO LORAN-C IN ALL REGIONS EXCEPT OMEGA USED TO PROVIDE OCEANIC COVERAGE
3 TRANSITION TO GPS ALL REGIONS
4 TRANSITION TO GPS ALL REGIONS EXCEPT USERS WITH LOW COST AVIONICS (CATEGORIES 1 and 2) IN CONUS AND ALASKA
BASELINE CASE - MAINTAIN 2ND GENERATION VOR IN CONUS AND ALASKA, AND OMEGA IN OCEANIC AND OFF-SHORE REGIONS.


160
140
120
100
80
60
40
20
-20
-40
-60
-80



OPERATING REGIONS
CONUS
ALASKA
OCEANIC
ALASKA OFF SHORE
TOTAL THIS TYPE OF OPERATION
TOTAL ALL NAS USERS
CORRESPONDING FAA COST IMPACTS
2,977
14,295
70
463,749
672,021
PERCENT CHANGE IN CUMULATIVE PRESENT VALUE USER COSTS 1978 THROUGH 2005, RELATIVE TO BASELINE VALUE
PERCENT CHANGE IN CUMULATIVE PRESENT VALUE FAA COSTS 1978 THROUGH 2005, RELATIVE TO BASELINE CASE
160
140
120
100
80
60
40
20
0
-20
-40
-60
-80

line Case
S

for each of the 23 viable types of operation-operating region user group combinations that resulted when avionics category and aircraft type grouping criteria were not considered. The figure displays, for each of the four navigation alternatives' nominal scenarios, the percent change in cumulative (1978-2005) present value user costs relative to comparable costs produced by the nominal baseline scenario. Negative values mean a user cost reduction relative to the anticipated nominal baseline costs (which are also listed as a reference on the chart). The per cent change in FAA costs are also presented in the right hand column.

The numerical values associated with this chart are presented in Appendix C. Summary computer printouts, listing the annual user, FAA and total costs, both present value and after tax cash outlay for each of the 29 implementation scenarios evaluated, are also contained in Appendix C. Appendix D presents a complete printout for the nominal GPS scenario (Run 403).

6.3 SENSITIVITY ANALYSIS

To determine the significance of study guidelines and ground rules as well as input cost estimates on the study results, many of the study parameters were varied and the resulting FAA and user costs computed. These results were subsequently compared to the costs produced by the corresponding nominal production run using only nominal input and control values to ascertain the impact of the parameter modification in question. Table 6.2 summarizes these results. For example, deletion of the investment tax credit and depreciation (change number 1 of Table 6.2) would result in an increase of 61.80% in the cumulative 1978-2005 user after tax cash outlay costs relative to the costs of the nominal baseline scenario (Run 100) and 51.85% relative to the costs of the nominal GPS scenario (Run 403). Generally, this nominal GPS scenario was used as a representative of the other navigation alternatives with their sensitivity values expected to lie between those of the baseline (100) and GPS (403) cases. The results of each of the

Table 6.2

Cost Sensitivity Summary
(Percent User and FAA Cost Changes Relative to
Corresponding to Nominal Production Run)

[illegible]		RUN NUMBER NOMINAL CHANGE RUN	[illegible]*					
			AFTER TAX CASH OUTLAY			PRESENT VALUE		
NO.	[illegible]		USERS	FAA	TOTAL	USERS	FAA	TOTAL
	NOMINAL [illegible]	[illegible]						
	DELETE INVESTMENT TAX [illegible] DEPRECIATION FOR ALL [illegible] GROUPS	[illegible] 403-[illegible]	[illegible] 80 [illegible]	[illegible] 0 00	36 83 4[illegible] 60	[illegible] 48 78	[illegible]	[illegible]
	[illegible] INVESTMENT TAX [illegible] DEPRECIATION FOR [illegible]	[illegible]	[illegible]	[illegible]	99 94 [illegible] 65	22[illegible] 60[illegible]	[illegible]	[illegible]
	[illegible] IMPROVEMENT [illegible]	[illegible]	[illegible] 24 82	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4	DECREASE AVIONICS ANNUAL [illegible] IMPROVEMENT [illegible] REDUCTION [illegible]	[illegible]	[illegible] [illegible] 36	[illegible]	[illegible] 47 44 [illegible]	4 5 4[illegible] 25	[illegible]	[illegible]
	INCREASE ANNUAL INFLATION RATE FROM [illegible] TO [illegible]	[illegible] 403-5	[illegible]	63 4[illegible] 45 05	66 81 68 46	46 00 55 24	33 66 27 36	40 [illegible] 46
	DECREASE ANNUAL INFLATION RATE FROM 7.00 TO 4.00	100-6 403-6	[illegible] [illegible]	35 97 [illegible]8 95	-38 07 -39 3[illegible]	-29 66 -34 13	-21 87 19 41	[illegible] -24 [illegible]
	DECREASE ANNUAL INFLATION RATE FROM 7.00 TO [illegible]	100-[illegible] 403-[illegible] 40[illegible]	[illegible] [illegible] [illegible]	-6[illegible] 55 -52 59 -6[illegible]	-65.24 [illegible] 43 -66.60	-54.42 -60.89 -57.45	-40.52 -37 26 -4[illegible] 55	-46 4 [illegible] [illegible]
	ELIMINATE [illegible] PRODUCTION COST FACTOR [illegible]	[illegible]	[illegible] 52 [illegible] 6	0 00 0 00	-6 26 [illegible]	[illegible] -14 38	0 00 0 00	[illegible]
9	INCREASE VOLUME PRODUCED TO DATE DISCOUNT COEFFICIENT FROM 0.90 TO 0.95	100-8 403-8	[illegible] [illegible] 55	0 00 0 00	[illegible] 48 41 36	[illegible] 38 95	[illegible] 00 0 00	[illegible]
10	DECREASE VOLUME PRODUCED TO DATE DISCOUNT COEFFICIENT FROM 0.90 TO 0.85	100-9 403-9	[illegible] -33 98	[illegible] 00 [illegible] 00	[illegible] -27 26	[illegible] -25 3[illegible]	0 00 [illegible]	[illegible] [illegible]8
11	DECREASE GPS AVIONICS COSTS TO 0.75 OF NOMINAL	403-10 40[illegible]-10	-22 [illegible] [illegible]	[illegible] 0 00	[illegible] 75 [illegible] 62	[illegible]	[illegible] 00	[illegible]
12	DECREASE GPS AVIONICS COSTS TO 0.50 OF NOMINAL	403-11 40[illegible]-11	-44 [illegible] -30 56	0 00 [illegible]	35 51 2[illegible]	4[illegible]4 [illegible]3 22	[illegible]	[illegible]4
13	DECREASE GPS AVIONICS COSTS TO 0.25 OF NOMINAL	403-12 40[illegible]-12	[illegible] 40 [illegible] 62	[illegible]	5[illegible] [illegible] 45	[illegible] 4 [illegible]	[illegible]	[illegible]
14	FAA PAYS 10% OF NON-FAA GPS RECURRING COSTS	403-13 4[illegible]-13	0 00 [illegible]	[illegible]	[illegible]	[illegible]	22 [illegible] [illegible] 63	[illegible]
15	FAA PAYS 20% OF NON-FAA GPS RECURRING COSTS	403-14 40[illegible]-14	[illegible] 00 [illegible] 00	39 [illegible] [illegible]	21 [illegible]8 26 [illegible]	[illegible]	45 4[illegible] 41 [illegible]	[illegible]
16	INCREASE ANNUAL NEW AND RETIRED AIRCRAFT BY 15%	100-15 403-15	8 36 8 47	[illegible] 00 0 00	[illegible]	[illegible] [illegible] 42	0 00 [illegible] 00	[illegible]
17	DECREASE ANNUAL NEW AND RETIRED AIRCRAFT BY 15%	100-16 403-16	-8 34 -8 87	0 00 0 00	[illegible]	-8 [illegible] [illegible] 40	0 00 0 00	4 [illegible] [illegible] 44
18	REPLACE GPS COSTS BY DIFFERENTIAL GPS COSTS	403-17	3[illegible] 00	45 3[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	DELETE SELF CONTAINED OMEGA FAA IMPLEMENTATION AND RECURRING COSTS	[illegible]	[illegible]	5 36 5 58	[illegible]	[illegible]	5 0[illegible] 4 [illegible]	[illegible]
	[illegible] FAA [illegible] FROM [illegible] YEAR AFTER TRANSITION [illegible] 5	405-[illegible] 406-[illegible] 40[illegible] 408-[illegible] 4[illegible] 4[illegible] 4[illegible]	[illegible] [illegible] [illegible] 0 00 [illegible] 0 00 0 00	[illegible] [illegible] [illegible] 55 [illegible] 64 [illegible] [illegible] 12 [illegible]	4 [illegible] [illegible] [illegible] 56 [illegible] 84 [illegible] [illegible] [illegible]	[illegible]	[illegible] 4 [illegible] [illegible] [illegible] [illegible] [illegible] 4 [illegible]	[illegible]
	[illegible] FAA [illegible] FROM [illegible] YEAR AFTER TRANSITION [illegible]	405-20 406-20 40[illegible] 408-20 4[illegible]-20 4[illegible] 4[illegible]	[illegible] 0 00 [illegible] [illegible] [illegible] 0 00 0 00	[illegible] 4 [illegible] [illegible] [illegible] [illegible] 7 [illegible] 4 35	[illegible] [illegible] [illegible] [illegible] 68 [illegible] [illegible] [illegible]	[illegible]	14 4[illegible] [illegible] 4 [illegible] 4 [illegible] 4 [illegible] [illegible] [illegible]	[illegible]

*Relative to corresponding nominal production run

changes listed in Table 6.2 are combined, when appropriate, and presented in the following series of cost sensitivity displays. These sensitivities are divided into two groups, those that are applicable to all of the navigation system alternatives examined and those relevant only to the GPS alternatives.

6.3.1 General Sensitivity Examples

Figure 6.10 presents cost impacts that result from: (a) deletion of the investment tax credit and avionics depreciation (condition 2), and (b) the additional deletion of improved technology and avionics production base cost reduction factors (condition 3). The resulting baseline and GPS costs are compared to the costs resulting from the nominal, i.e., unmodified, baseline and GPS scenarios, respectively.

Generally, three cost scales are used on these charts. The right scale is used to determine the per cent change relative to both the nominal baseline and GPS cases. The middle scale permits determination of cumulative present value dollar impact on the baseline case. The left scale performs a similar function for the nominal GPS case. GPS user costs increase to a much greater degree than the baseline user costs for condition 3 because of the impact of the production base cost reduction factor. Most of the baseline avionics exceeded the 20,000 unit cutoff in 1978, while GPS avionics, with a negligible 1978 production base, realized a substantial reduction in purchase price during the RAANS planning period.

The impact of varying the annual technology improvement cost reduction factor from 3% to 8% per year is displayed in Figure 6.11. No significant difference is observed between the baseline and GPS examples.

The impact of varying inflation rate is displayed in Figure 6.12. The slight differences between GPS and the baseline costs result from their different distribution of expenses over the

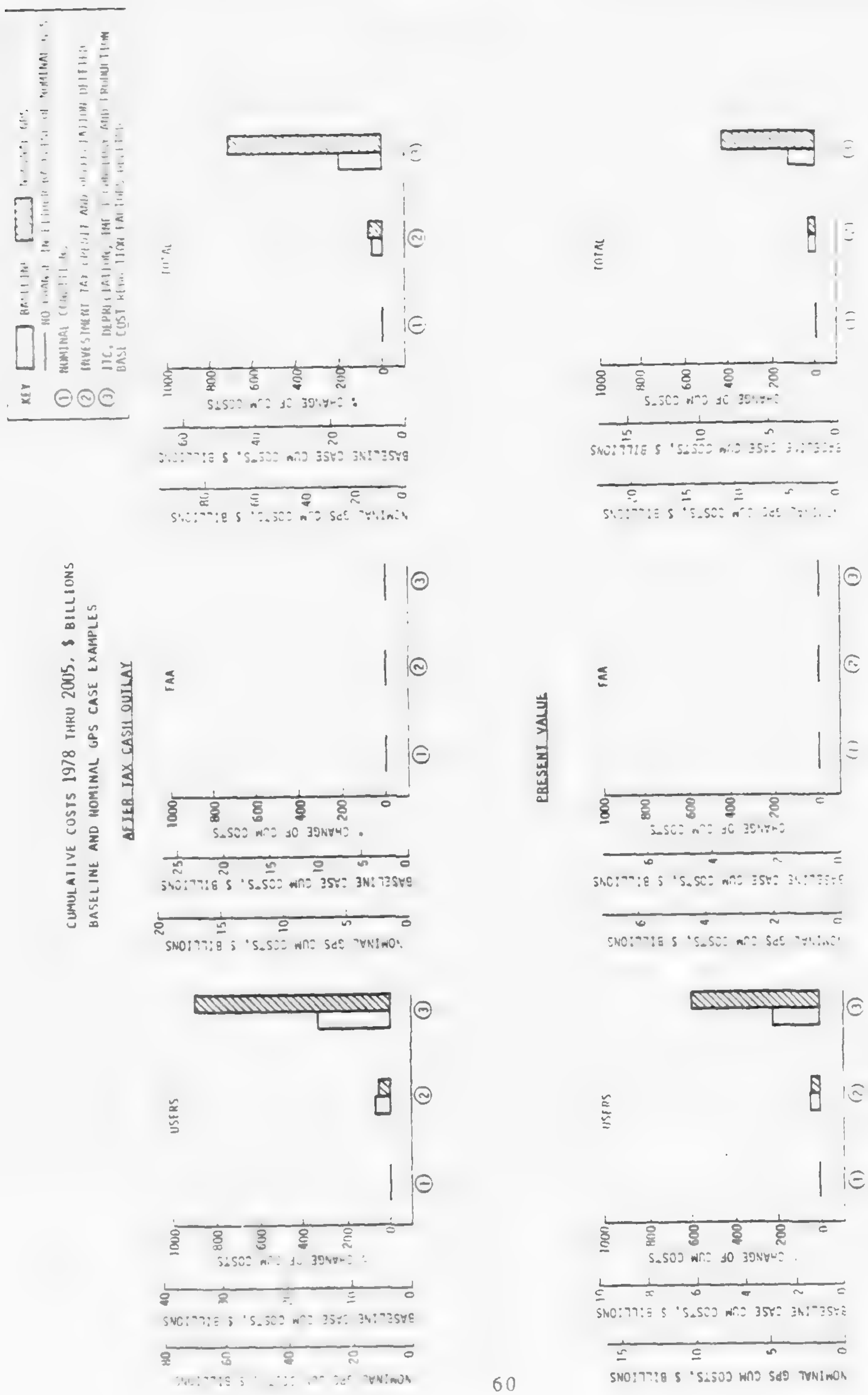


Figure 6.10 User and FAA Cost Sensitivity to the Use of Investment Tax Credit, Depreciation, Avionics Improved Technology Cost Reduction Factor, and Avionics Cumulative Production Cost Reduction Factor

3. Provide a fail safe backup system (in case of satellite

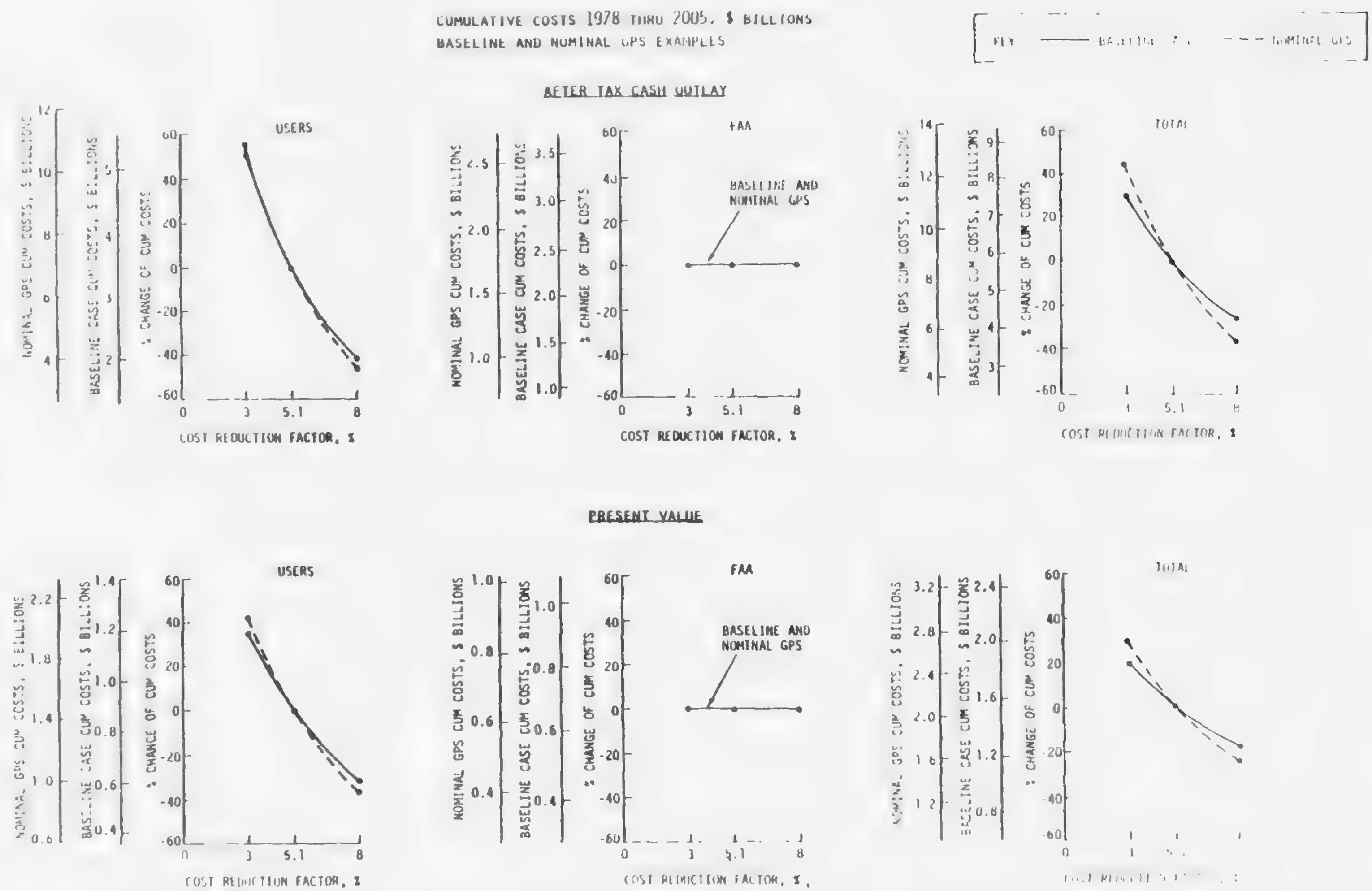


Figure 6.11 User and FAA Cost Sensitivity to the Value of Improved Technology Cost Reduction Factor (Nominal Technology Factor = -5.1% per Year)

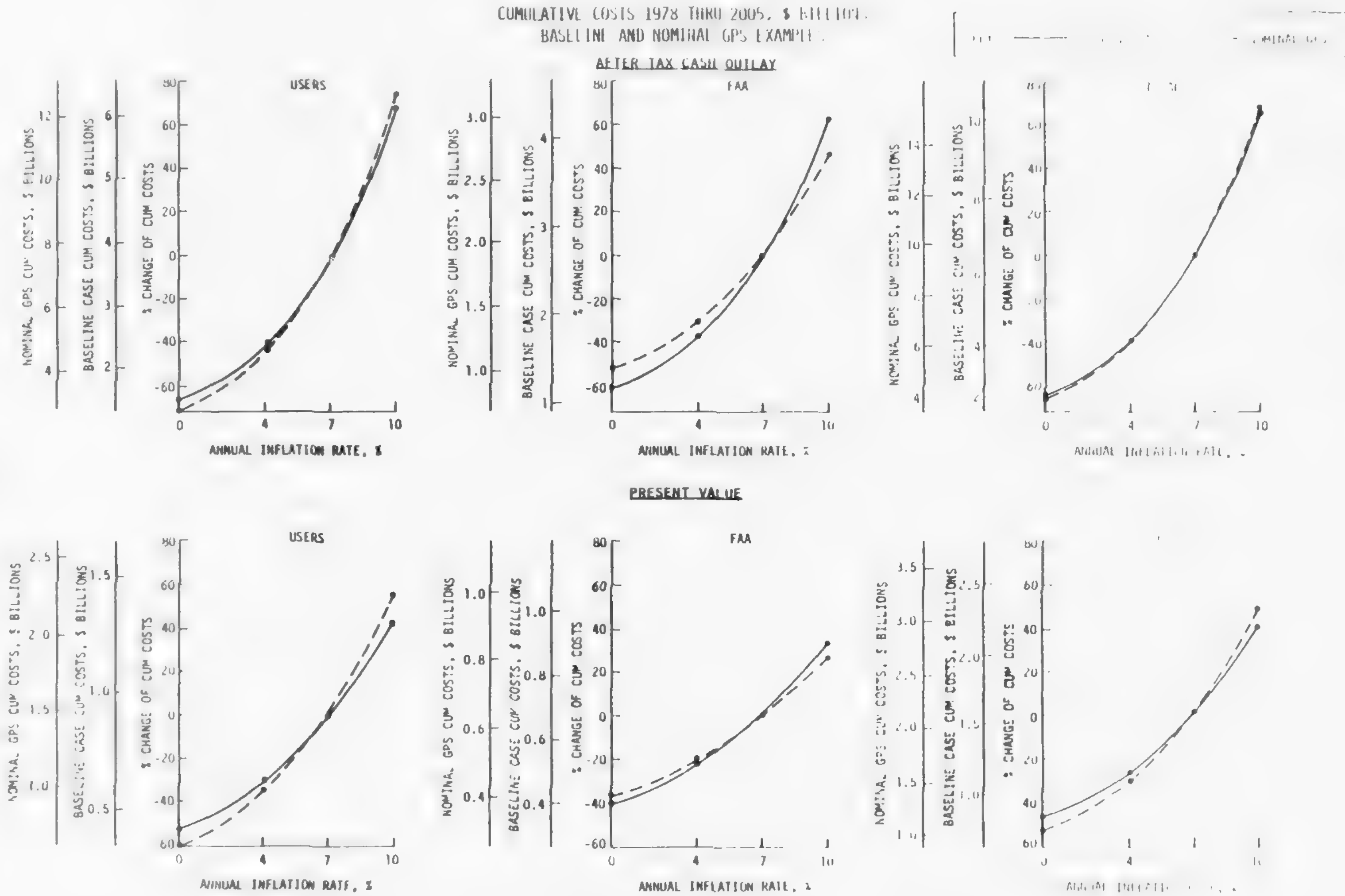


Figure 6.12 User and FAA Cost Sensitivity to Annual Inflation Rate
(Nominal Inflation Rate = 7%)

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RAANS planning period and the compounding effect of the specified annual inflation rate. The effect of inflation on cumulative user and FAA costs is illustrated in Figure 6.13 using the baseline and nominal GPS scenario examples.

The impact of present value discount rate on cumulative preser value cost is displayed in Figure 6.14. The zero percent discount rate produces the same totals as the after tax cash outlay values.

Figure 6.15 illustrates the effect of removing the production base cost reduction factor, 20,000 unit cutoff. GPS realizes a greater benefit than the baseline users since the GPS avionics started with a lower production base in 1978 than did the baseline avionics. Charts displaying the number of avionics packages sold for each of the nominal alternative system scenarios are provided in Appendix C. The effect of the variation of production base cost reduction factor between 0.85 and 0.95 (see Appendix B for derivation of nominal value, 0.90) is illustrated in Figure 6.16. Again, the baseline costs are not too sensitive to this parameter because the original avionics production base for many units exceeded the 20,000 unit cutoff in 1978.

The impact of aircraft fleet size forecasts are examined in Figure 6.17 for both the nominal baseline and GPS cases.

A RAANS study ground rule was that the self-contained navigation system (INS, Doppler radar, etc.) would not induce a FAA annual recurring cost. When Omega was substituted for self-contained (Section 6.1), both Omega implementation and annual recurring costs were assessed against the FAA for the appropriate operating regions. Figure 6.18 depicts the impact of removing these costs from both the nominal GPS and Loran-C cases.

6.3.2 GPS Related Sensitivities

The effect of reducing the RAANS GPS avionics cost estimates is illustrated in Figure 6.19 for both the GPS and GPS plus VOR for CONUS and Alaskan low cost avionics nominal implementation

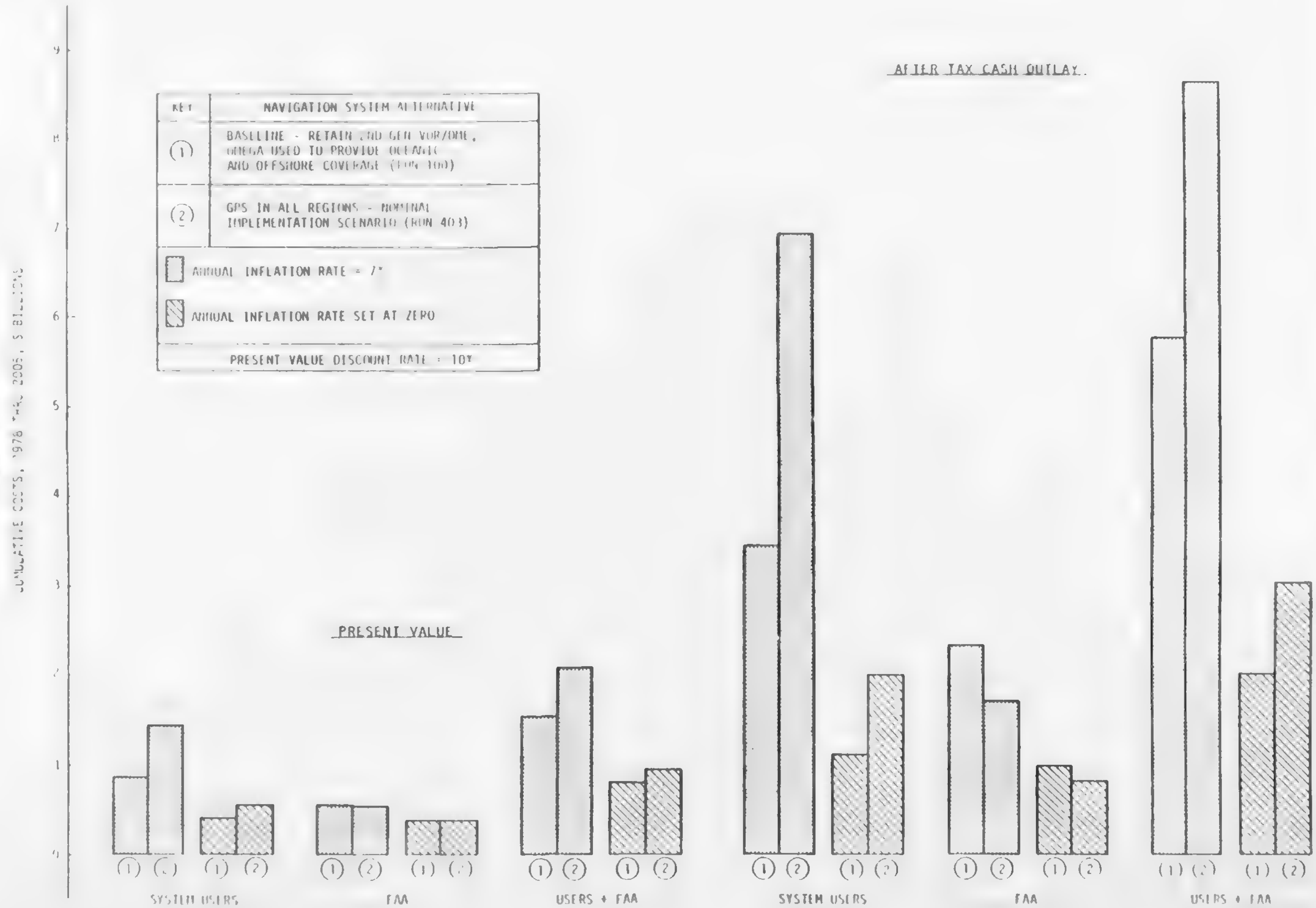

Figure 6.13 Impact of Inflation on User and FAA Cumulative Costs (1978-2005)

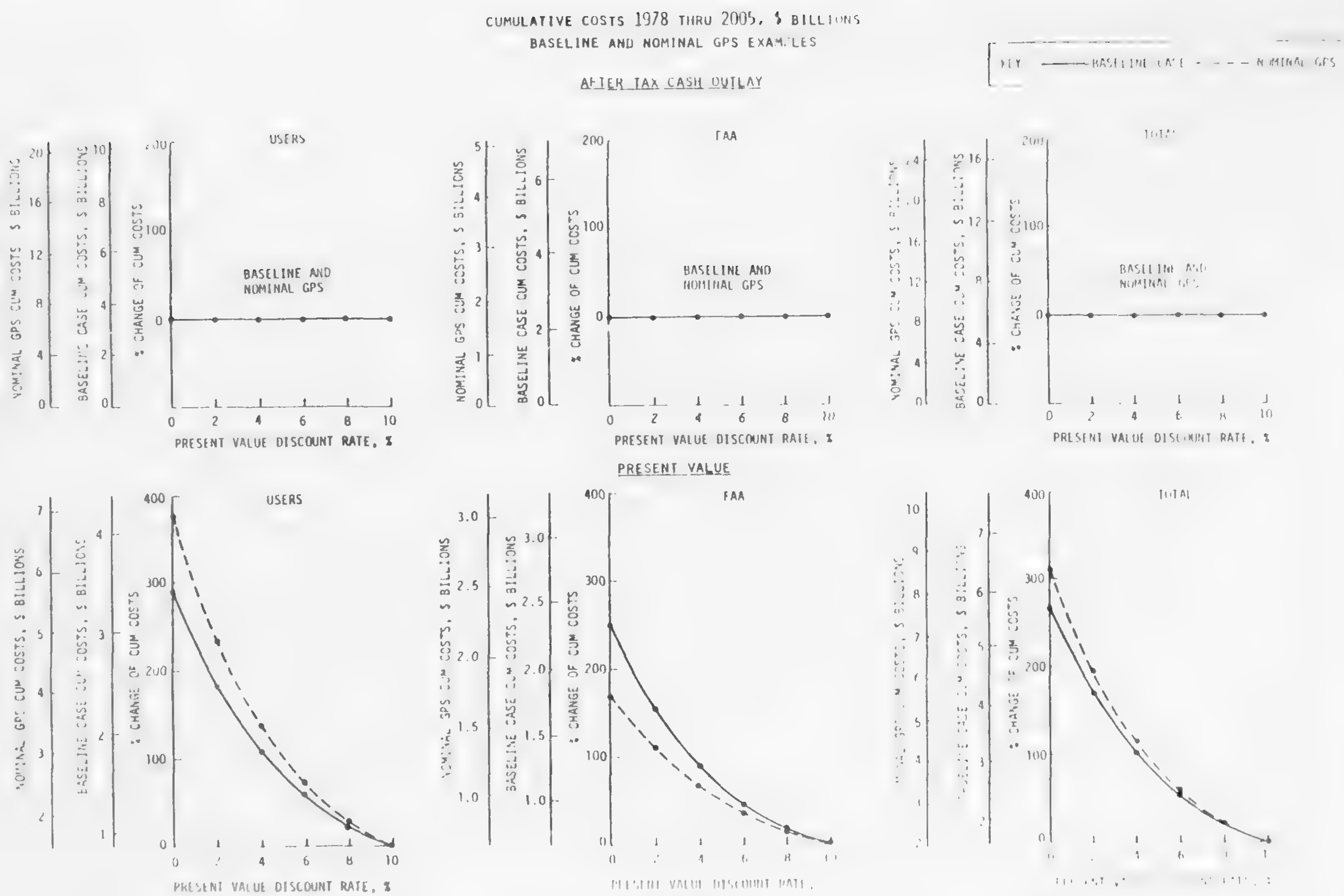

Figure 6.14 User and FAA Cost Sensitivity to Present Value Discount Rate, Relative to Nominal Present Value Discount Rate of 10%

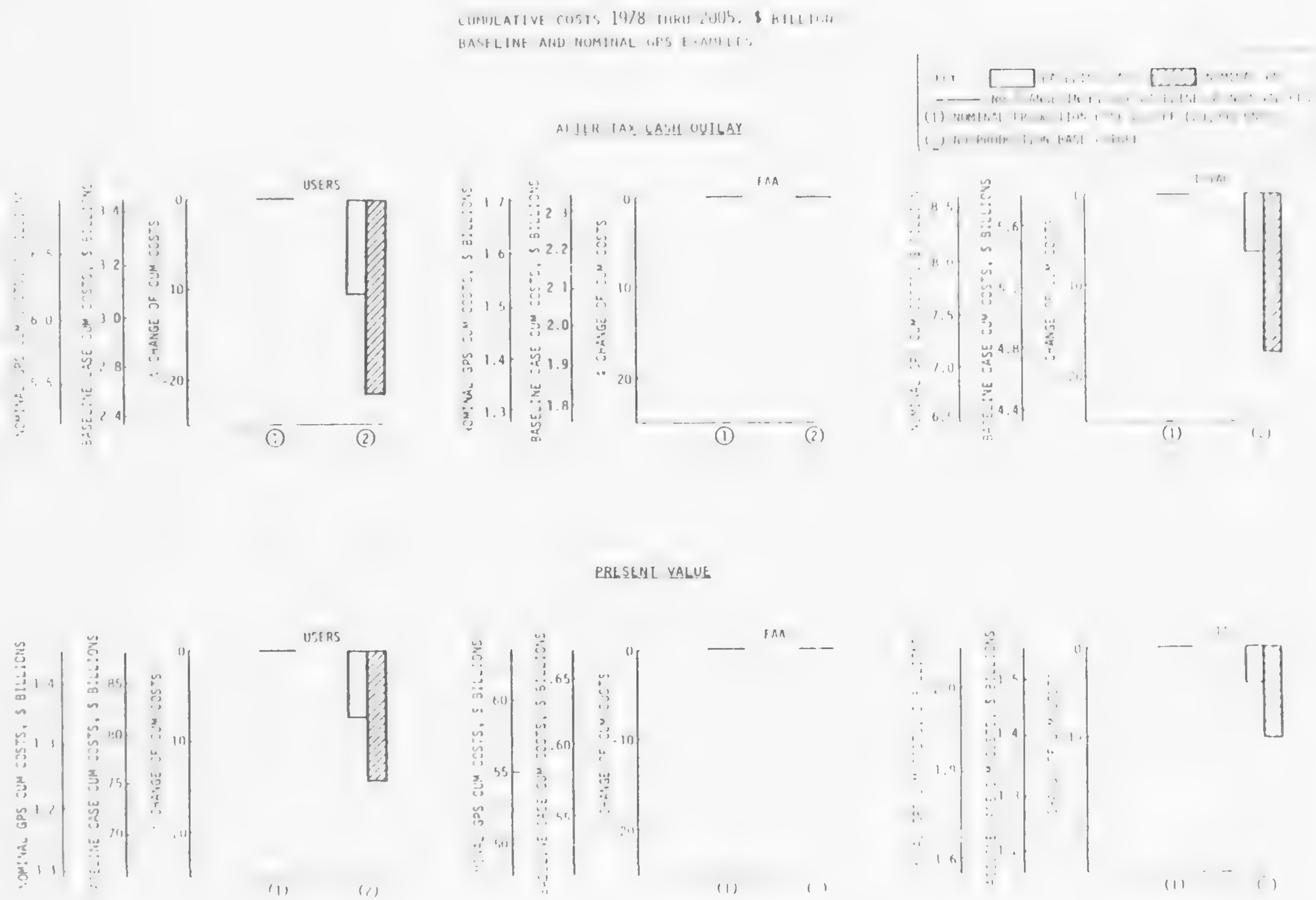

Figure 6.15 User and FAA Cost Sensitivity to the Production Cut off Value Applied to Avionics Cumulative Production Cost Reduction Factor

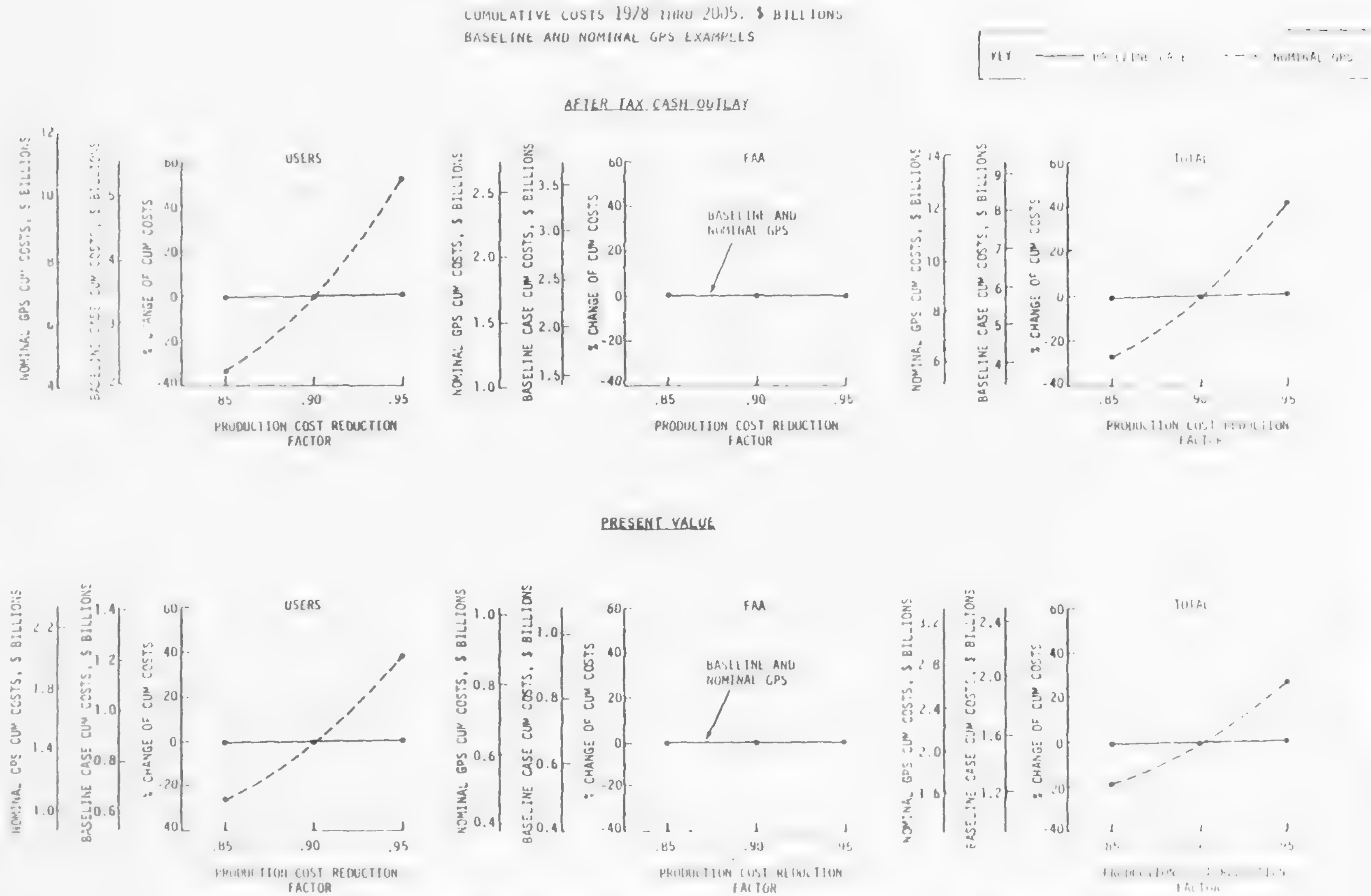

Figure 6.16 User and FAA Cost Sensitivity to the Value of Cumulative Production Cost Reduction Factor (Nominal Production Cost Factor = 0.90)

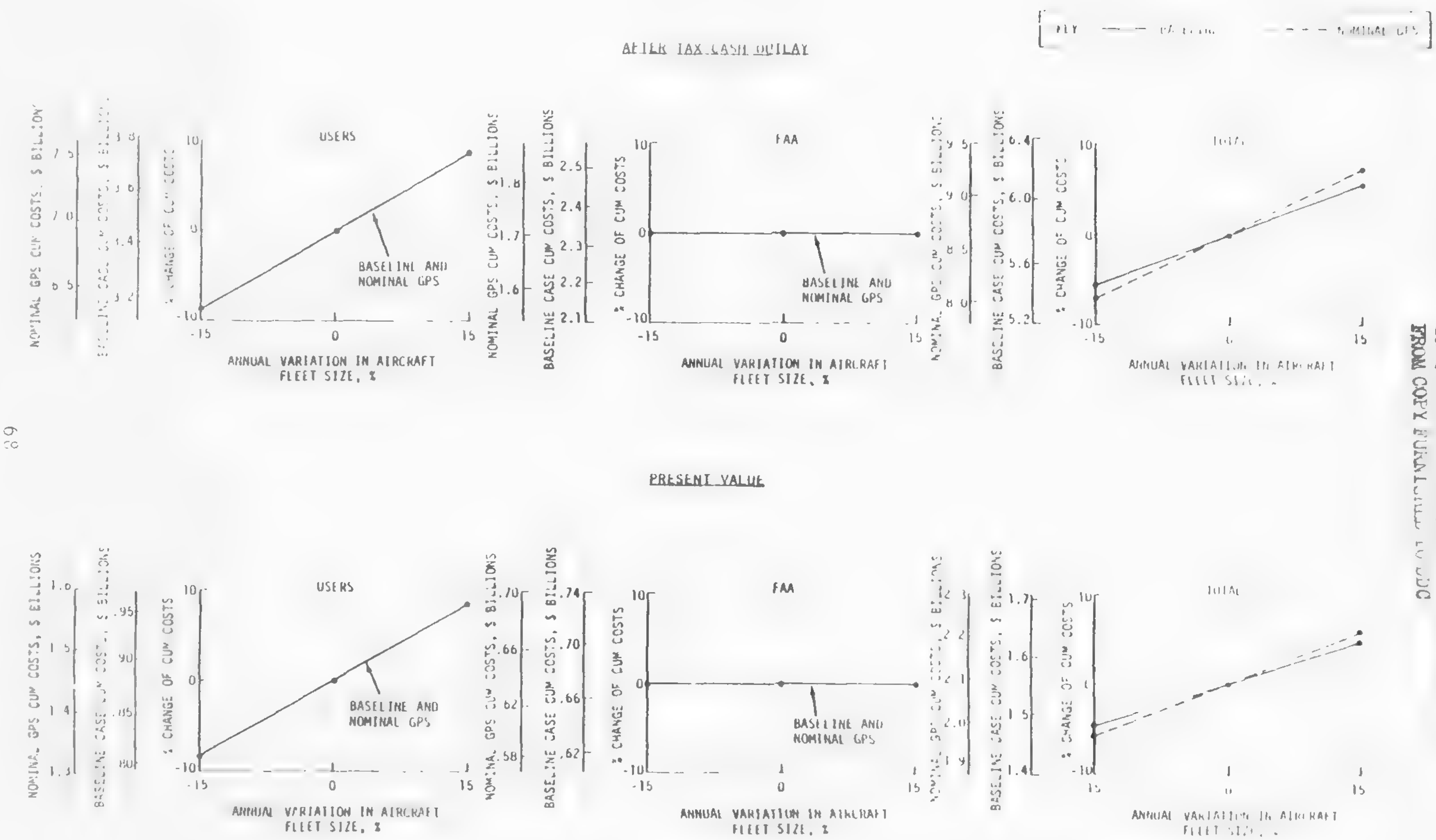

Figure 6.17 User and FAA Cost Sensitivity to Variations in Annual Aircraft Fleet Size Growth Projections

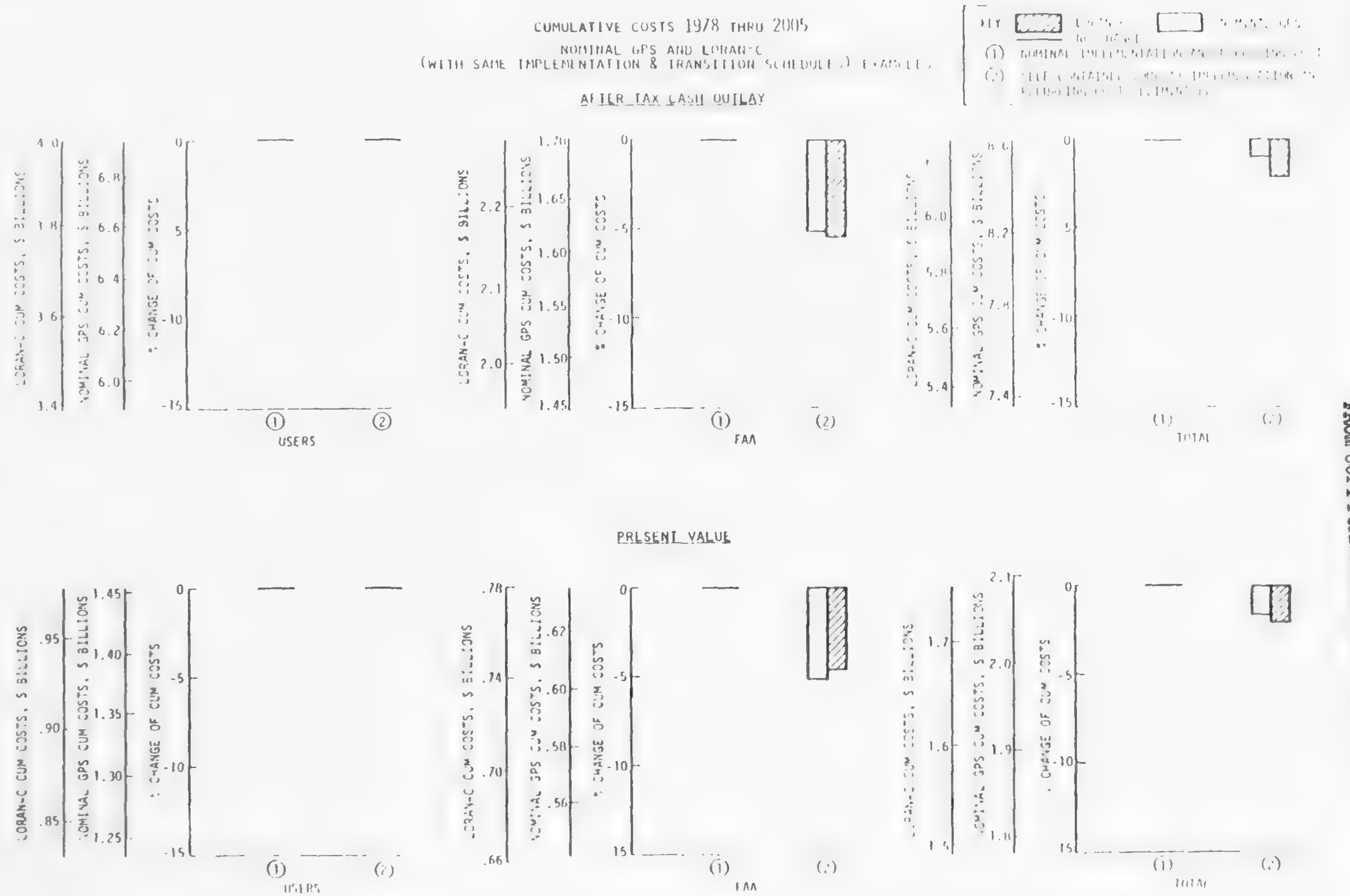

Figure 6.18 User and FAA Cost Sensitivity to Elimination of FAA "Self-Contained

CUMULATIVE COSTS 1978 THRU 2005, $ BILLIONS
NOMINAL GPS AND NOMINAL GPS WITH LOW COST VOR EXAMPLES

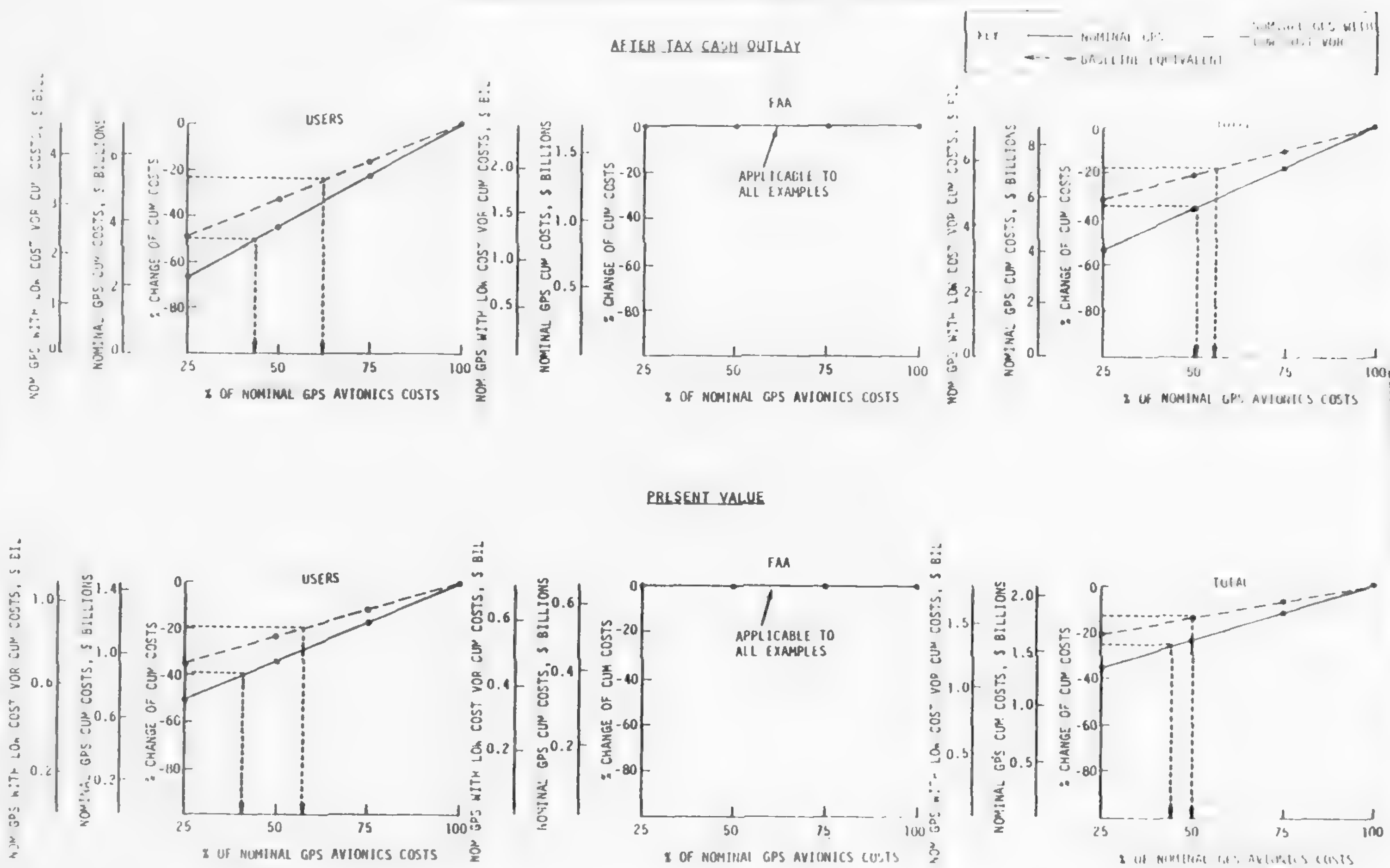

Figure 5.19 User and FAA Cost Sensitivity to GPS Avionics Cost

scenarios. To achieve user costs equivalent to the baseline costs, the RAANS GPS avionics costs would have to be reduced to roughly 40 and 60 per cent of their nominal cost for the GPS and GPS plus VOR scenarios, respectively.

The impact on FAA costs of having the FAA assume a portion of DOD's GPS annual recurring costs is illustrated in Figure 6.20.

The possibility exists in the GPS plus low cost avionics VOR scenario to diminish the scope of the CONUS and Alaska VOR system once the transition to GPS has been completed. In this scenario, the remaining VOR system will only have to serve the low cost avionics users (RAANS avionics categories 1 and 2 - VFR and low cost GA, respectively). Figure 6.21 indicates the per cent change of 1978 to 2005 cumulative costs that result from specified reductions in VOR system annual recurring costs to be started at the <u>end</u> of the transition to GPS. Three implementation/transition schedule cases are displayed.

A differential GPS system has been informally proposed as a means of reducing user's GPS avionics costs. This system configuration has been defined as an alternative to the current approach which utilizes two frequencies, two signals (C/A and P) and a pseudo random noise (PRN) modulation technique. This approach would assume:

(1) a civil transmitter on each satellite, and

(2) an inverted capability (uplink).

These features were considered likely to reduce the cost of user avionics relative to those estimated for GPS in this study. In summary, the following are the advantages that might possibly be derived by these system modifications:

(1) Higher down link power budget which would require less costly aircraft antennas and/or less sensitive and complex signal processing.

(2) A reduction in avionic memory and computation requirements which would be performed on the ground and data linked up to the aircraft (mother-daughter concepts).

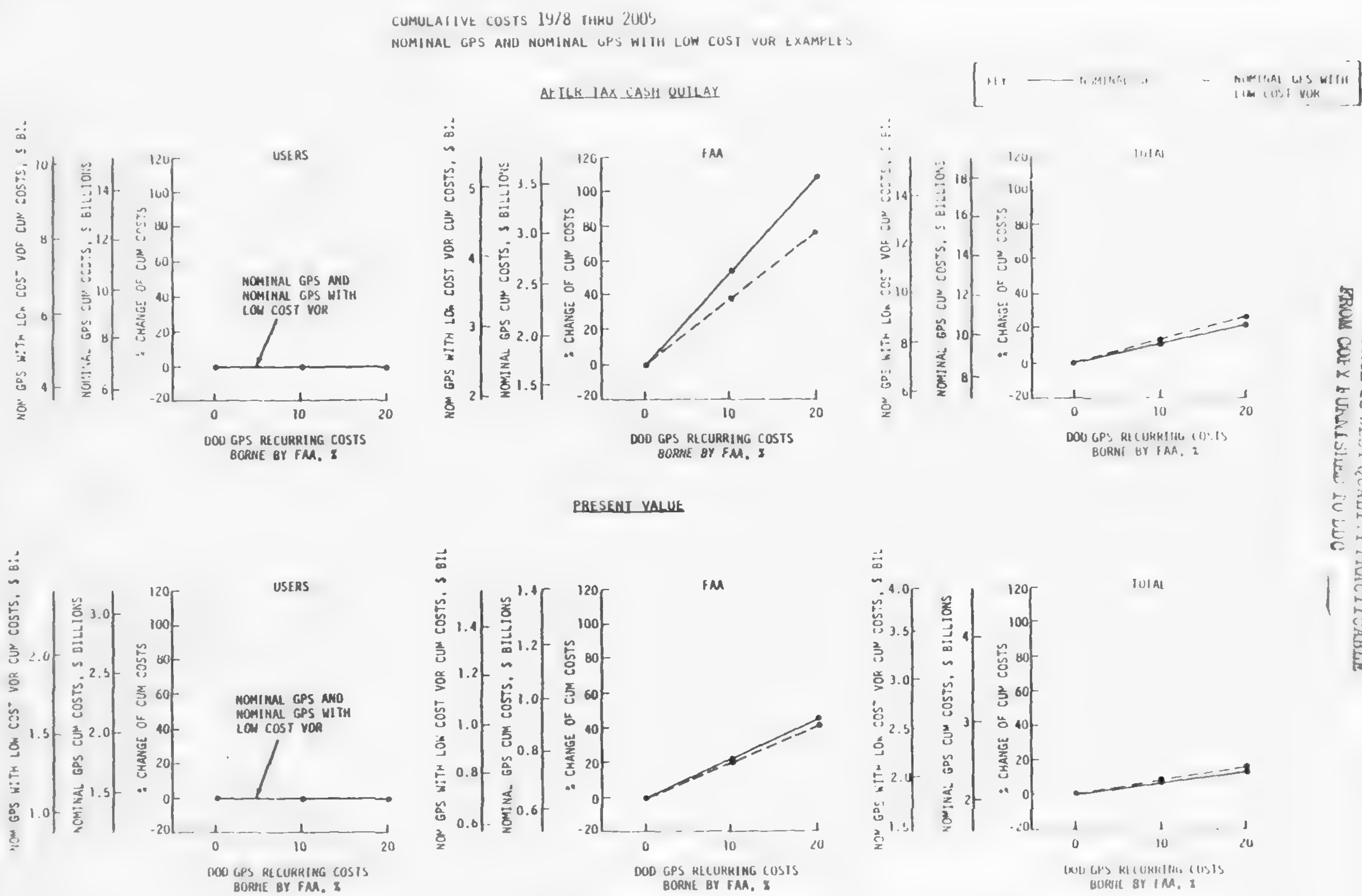

Figure 6.20 User and FAA Cost Sensitivity to Percent of DOD GPS Recurring Costs Borne by the FAA

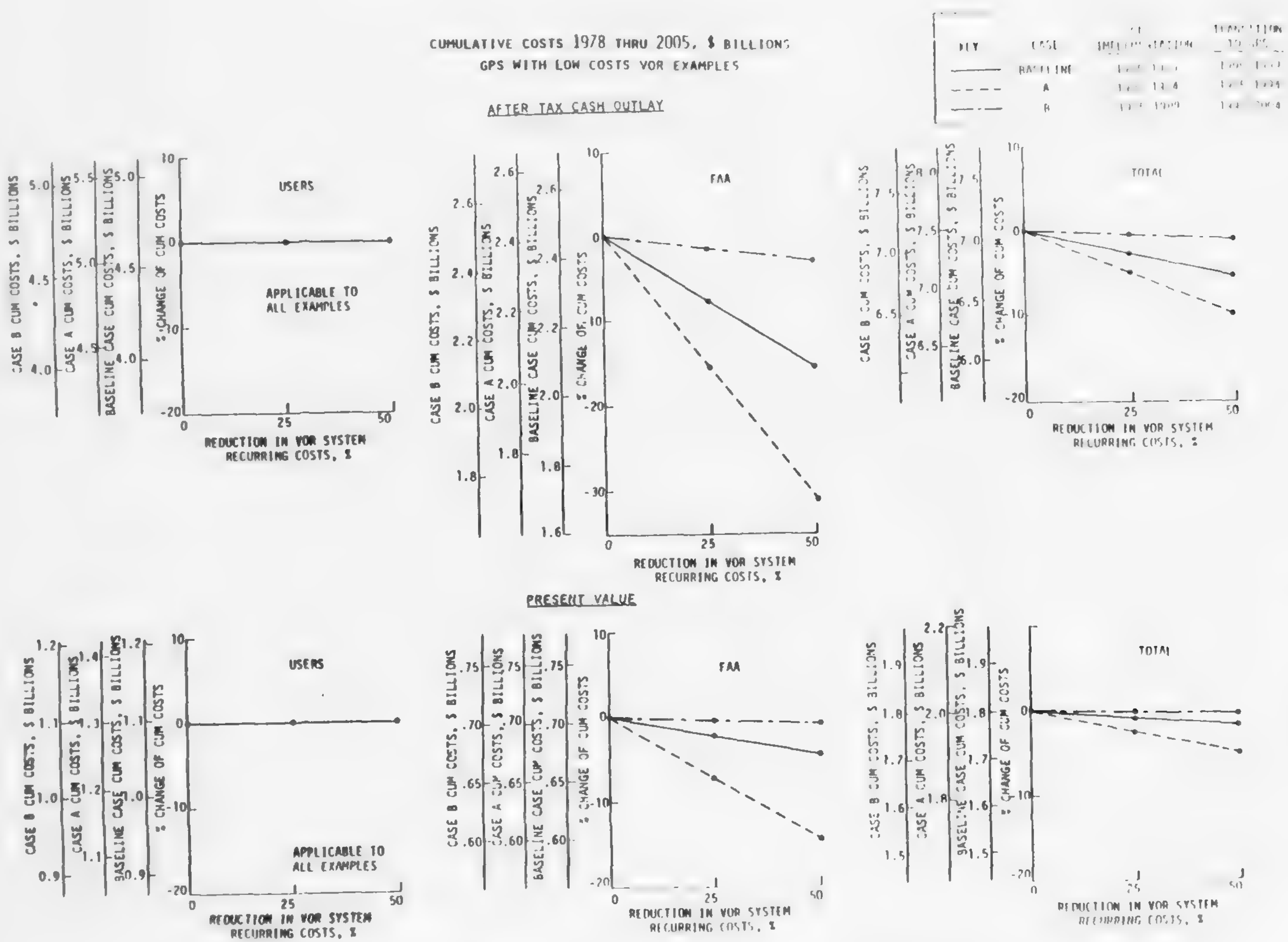

Figure 6.21 Comparison of Alternative Baseline Scenarios
7% Inflation, 10% Present Value Discount Rate

(3) Provide a fail safe backup system (in case of satellite failure).

(4) Minimize the number of frequencies required (L_1 only) and uplink atmospheric correction which need both L_1 and L_2 (ionospheric corrections).

(5) Provide a precision signal independent of the military "P" code.

(6) Minimize transition and international problems by allowing both systems to operate with the current VOR/DME system without significant increase.

The differential GPS input costs (estimated by the RAANS Support Team), namely system implementation and annual recurring costs and the associated avionics component costs, are presented in Table 6.3. The nominal RAANS GPS costs are also listed for comparison purposes.

Cost comparisons of both the GPS and differential GPS costs relative to those of the nominal baseline case are depicted in Figure 6.22. Though substantially reduced relative to GPS, the differential GPS user costs still exceed those of the baseline. Differential GPS FAA costs are greater than the corresponding GPS costs by an amount only slightly less than the user (GPS to differential GPS) cost difference, thereby producing only slightly lower user plus FAA totals. A direct comparison of differential GPS to GPS costs is presented in Figure 6.23. The compensating tradeoffs bewteen the user and FAA costs are readily apparent.

Summary computer printouts, listing the annual user, FAA and total costs both present value and after tax cash outlay for each of the cases required for the previous sensitivity analysis are contained in Appendix C.

Table 6.3

Comparison of GPS and Differential GPS Avionics and System Costs

SYSTEM	GPS - DIFFERENTIAL GPS COST COMPARISONS RAANS AVIONICS CATEGORY COSTS		
	RAANS AVIONICS CATEGORY	1977 PRICE/PKG.	PKG. PRICE AT 20,000
GPS	1	$ 14,331	$ 5,765
	2	28.662	11,530
	3	31,035	12,484
	4	42,166	16,961
	5	33,408	13,438
	6	50,924	20,484
	7	115,360	46,402
	8	115,360	46,402
	9	115,360	46,402
	10	115,360	46,402
DIFF. GPS	1	$ 7,454	$ 2,999
	2	14,908	5,997
	3	16,412	6,642
	4	22,871	9,200
	5	18,116	7,288
	6	27,626	11,113
	7	64,444	25,924
	8	64,444	25,924
	9	64,444	25,924
	10	64,444	25,924

SYSTEM	GPS - DIFFERENTIAL GPS COST COMPARISONS AVIONICS COMPONENT COSTS			
	AVIONICS COMPONENT	PRIOR SALES	1977 PRICE	PRICE AT 20,000 UNITS
GPS	GPS (A)	50	$14,331	$ 5,765
	GPS (B)	50	16,704	6,719
	GPS (C)	50	25,462	10,242
	GPS (D)	50	57,680	23,201
DIFF. GPS	DIF. GPS (A)	50	$ 7,454	$ 2,998
	DIF. GPS (B)	50	9,058	3,644
	DIF. GPS (C)	50	13,813	5,556
	DIF. GPS (D)	50	32,222	12.961

REGION	GPS - DIFFERENTIAL GPS COST COMPARISONS (MILLIONS OF 1977 DOLLARS)			
	NON-FAA		FAA	
	GPS	DIFF. GPS	GPS	DIFF. GPS
IMPLEMENTATION COSTS				
REGION IND.	763.00	763.00	7.50	68.50
CONUS	NA	NA	16.00	19.50
ALASKA	NA	NA	1.70	5.28
CONUS O.S.	NA	NA	3.90	10.30
AK O.S.	NA	NA	0.60	1.76
OCEANIC	NA	NA	0.60	0.60
RECURRING COSTS				
REGION IND.	127.00	127.00	1.10	16.10
CONUS	NA	NA	0.35	3.52
ALASKA	NA	NA	0.07	0.88
CONUS O.S.	NA	NA	0.14	1.04
AK O.S.	NA	NA	0.09	0.36
OCEANIC	NA	NA	0.11	0.11

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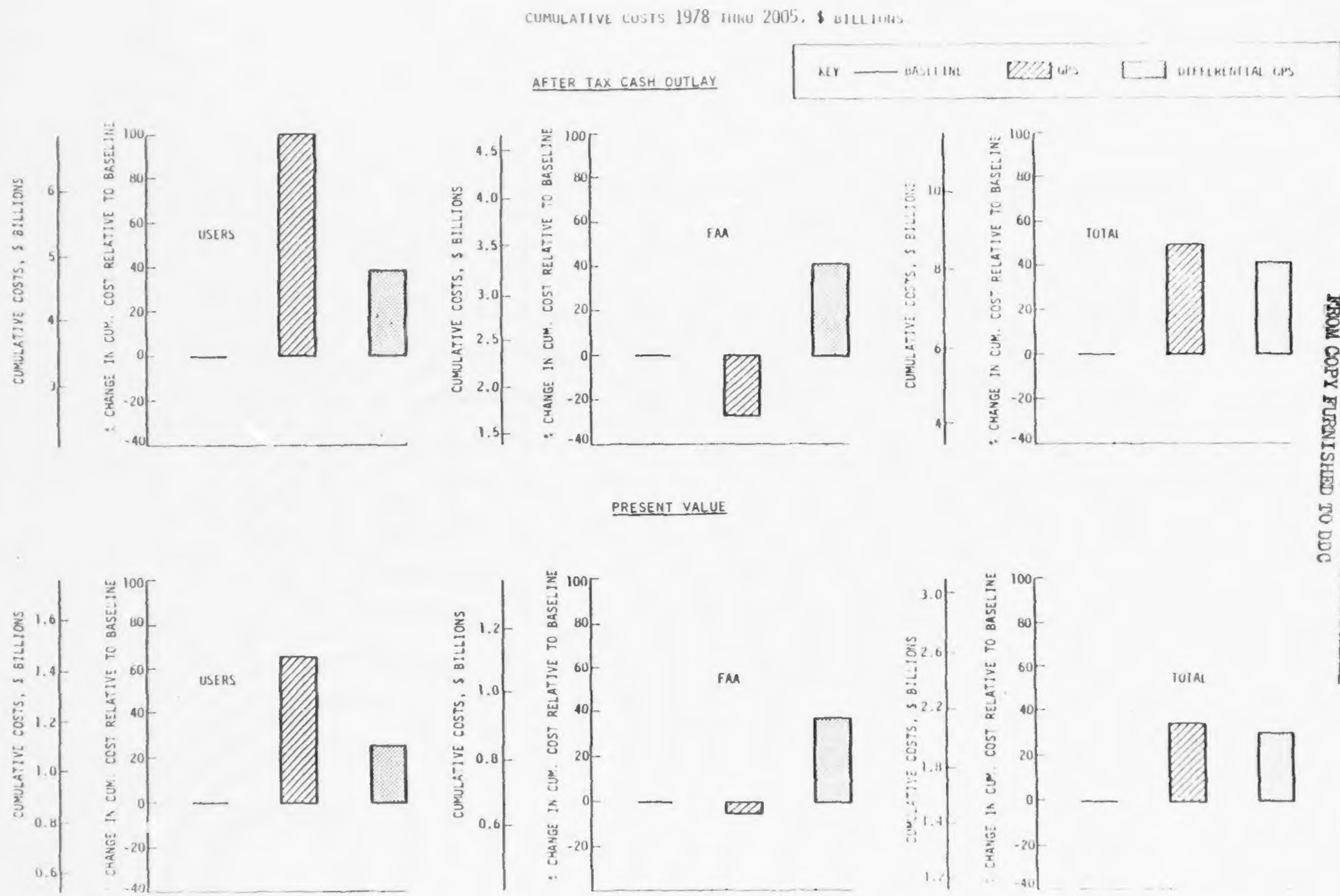

Figure 6.22 User and FAA Cost Comparison Between GPS and Differential GPS Systems

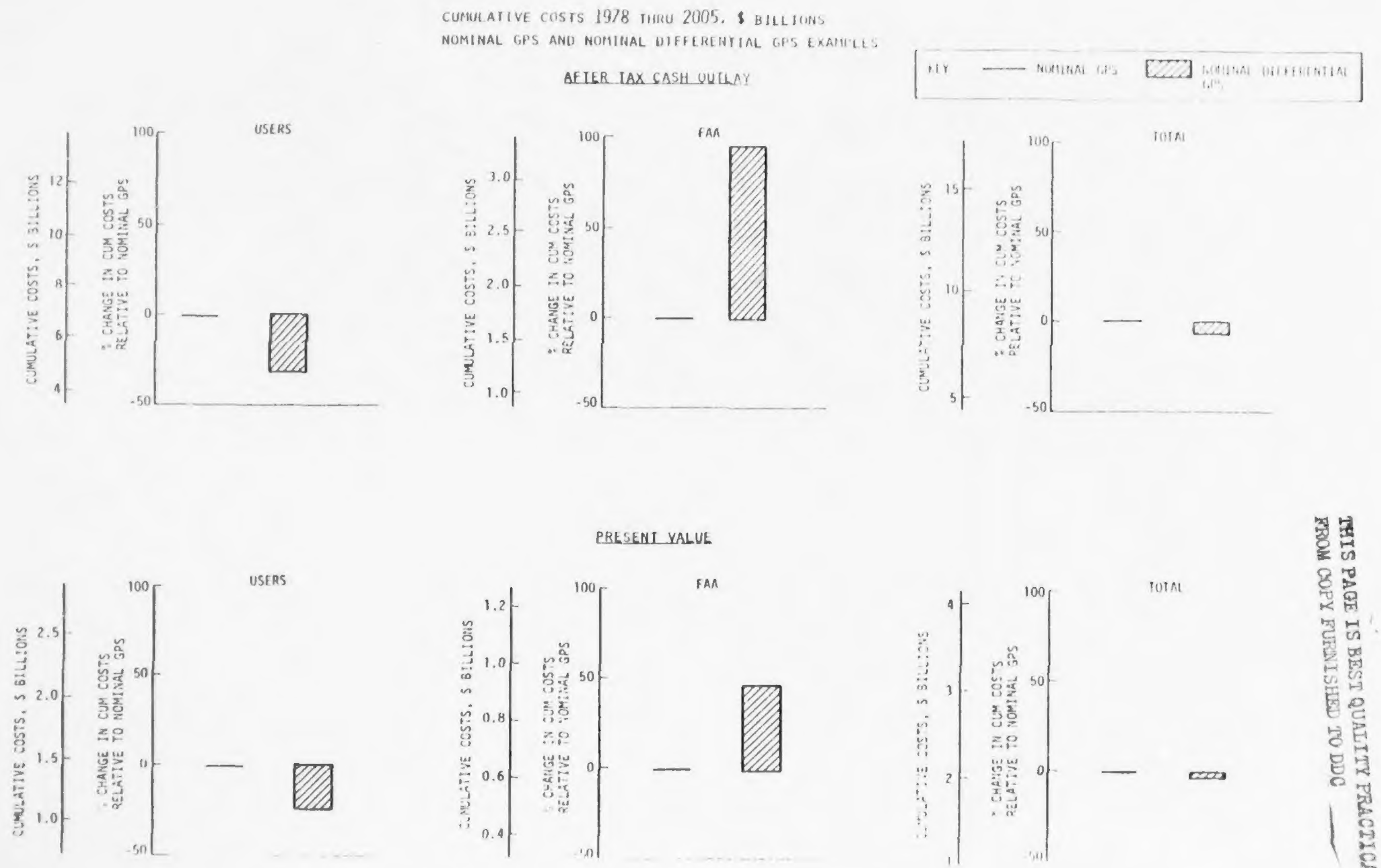

Figure 6.23 User and FAA Cost Sensitivity to Replacing GPS by "Differential GPS" Navigation System

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